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NPP Calibration and Product Validation Plan

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NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM (NPOESS) INTEGRATED PROGRAM OFFICE

and the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Calibration and Product Validation Plan

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1 Executive Summary

The calibration and product validation for the NPOESS Preparatory Project (NPP) focuses on (1) verification of instrument pre-launch characterization and post-launch calibration, (2) participation in the assessment of operational and science algorithms, (3) validation of operational and science products, and (4) participation in the evaluation of overall system performance.

This plan describes the structure and plans of the Government Team's contributions to the characterization, calibration and validation of the sensors, algorithms and data products of the NPOESS Preparatory Project (NPP). The Government Team consists of two coordinated activities; one funded and managed by the IPO Cal/Val Team, which is made up of the Science and Engineering Team from the IPO Internal Government Studies (IGS) Program and the IPO Operational Algorithm Teams (OATs). The second is NASA Cal/Val Team activities, conducted by the Global Change Science Team (GCST) and the NPP Calibration Support Team (NCST).

These activities will be, in turn, coordinated with those of the IPO's NPOESS Engineering and Manufacturing Development (EMD) contractor. The EMD contractor, called also the NPOESS Shared System Performance Responsibility (SSPR) contractor, has responsibility to develop the sensors, algorithms and data production systems, and to assure the quality of the resultant Environmental Data Records (EDRs). The SSPR contractor program will include the activities of the Sensor/Algorithm Subcontractors.

The Government Team's role is to provide government expertise where appropriate and to assess the final results on behalf of the U.S. government. The results of the Government Team's Calibration and Validation of Products activities described in this plan will provide support to the IPO in its evaluation of the SSPR performance and provide any suggestions for consideration of system and algorithm improvements.

For the purposes of this plan, the term "Government Team" refers to any or all of the groups listed above, e.g. IGS, OATs, GCST and NCST. A later version of this plan will detail the specific activities to be conducted by the specific groups.

1.1 The Government Team Activities

In order to accomplish its activities, the Government Team will participate in the performance verification of the NPP sensors. This requires timely access to contractor test plans, calibration algorithms and research and operational codes prior to the conduct of tests, and timely access to full test results. It is envisioned that the Government Team will be an active participant in the SSPR Contractor's Integrated Product Teams (IPTs).

The Government Team has prepared this NPP Calibration and Product Validation Plan for defining their role in the NPP Calibration/Validation Process. This Plan will be made available to the SSPR contractor prior to the submission of the Contractor's Calibration/Validation Plan. The SSPR Contractor's Plan will define their role in a shared

NPP Calibration/Validation effort. This SSPR Contractor's Plan will serve as the basis for a portion of an acceptance test procedure for the Products produced in the system provided by the SSPR Contractor.

This plan is specific to the NPP mission and it addresses only those sensors (currently VIIRS, CrIS and ATMS) that are on NPP and their specific EDRs. The activities conducted under this plan will serve as pathfinder to the subsequent task of characterizing and calibrating the full suite of sensors and validating the full suite of EDRs during the NPOESS era.

The IPO and NASA activities will be separately funded and managed. The IPO activities will seek to validate the end-to-end system performance against the explicit requirements of the NPOESS as detailed in the Integrated Operational Requirements Document (IORD) and the specific details of the sensor and algorithm specifications. The NASA activities will seek to validate the system performance for certain data products for the purposes of global change research. The NASA activities will place greater emphasis on longer term, consistently processed data sets utilizing optimal ancillary data. The IPO activities emphasis will be on validating the operational products that are produced with more rapid data delivery and necessarily involves high-speed availability of ancillary data and high-performance execution of state-of-the-art-science algorithms. The NASA activities will contribute to the Government Team efforts to conduct the overall calibration and validation of the NPP instruments.

1.1.1 IPO Activities

The IPO will manage the NPP Calibration/Validation of RDR, SDR and EDR Products. The IPO Calibration/Validation Team consists of scientists and engineers of the NPOESS Internal Government Studies (IGS) and the NPOESS Operational Algorithms Teams (OATs). The IPO Calibration/Validation Team activities are funded by the IPO and managed by the IPO Chief Scientist. Participants include scientists and engineers from universities, government laboratories and centers and federally funded research and development centers. Key government participants are drawn from the NPOESS user agencies (DoD, DOC/NOAA and NASA) and the DOC/National Institute of Standards & Technology (NIST). Part of the NASA contribution is through this mechanism. The IPO airborne risk-reduction and Calibration/Validation program serves as a resource for both the IPO supported and NASA supported activities.

1.1.2 NASA Activities

The independently managed NASA activity utilizing NPP is primarily within the Global Change Science Team (GCST) which consists of a competed science team supported by NASA internally funded project activities. Key government participants are drawn from the NASA Goddard Space Flight Center, the Langley Research Center, and the Jet Propulsion Laboratory. The NASA airborne science program serves as a resource for both the IPO supported and NASA supported activities. A NASA Research Announcement (NRA) will be used to solicit proposals for specific activities (including Calibration/Validation) by university, government, and corporate investigators.

The Project Scientist will manage an NPP Calibration Support Team (NCST), to develop research quality Level 1B data products for VIIRS, CrIS, and ATMS. NCST will work with the government partners and the contractors to assure that the sensors are fully characterized and calibrated during the pre-launch and post-launch phases. NCST will conduct coordinated analyses of the data and instrument trending during the NPP mission, and share these results with the IPO and the sensor vendors in a timely manner.

1.2 NPP Calibration Validation Activities

The IPO will oversee the overall, operational generation of NPOESS products at the Interface Data Processing Segment (IDPS); the management of agency product evolution will be the responsibility of the NESDIS Product Oversight Panels, the DoD Product Panels and the IPO Integrated Product Team. Operational calibration, validation, and evolution of NPOESS products will rely heavily on the procedures and approaches demonstrated in the execution of this NPP Calibration and Validation Plan.

NASA will oversee the validation of research products and global change data sets generated by the GCST in the Science Data Segment (SDS). The results of the validation activities by the GCST will be incorporated to provide guidance to the IPO in its evaluation of the EMD performance and to suggest and/or provide algorithm improvements.

Pre-launch activities focus on development of validation procedures, preliminary validation of new algorithms (and radiative transfer models) using existing space-borne and airborne sensors, verification and characterization of instrument performance over the ranges of operation, and estimation of the precision, accuracy, and overall uncertainty of the derived products. An essential feature of the plan is NIST traceability. Post-launch emphasis is on sensor calibration and validation of data products, leading to algorithm refinement.

Validation will be conducted using independent means to assess uncertainties of geophysical data products derived from instrument system outputs. This is generally approached by direct comparison with independent correlative measurements from ground-based networks, comprehensive test sites, and field campaigns, along with comparisons with independent satellite retrieval products from instruments on the same and different platforms. It is essential to have an integrated strategy for validation, including contributions from airborne field campaigns, surface networks, as well as satellites.

1.2.1 Sensor Test Data

The Government Team will work closely with the vendors during the pre-launch testing and characterization to assure that the post-launch instrument performance is understood, and sensors' radiance is correctly assimilated and tested.

1.2.2 Simulated data

The Government Team will work closely with the vendors to assure that the sensors' radiance and EDRs are correctly simulated, and performance of EDRs' algorithms and quality of products are carefully tested using simulated data.

1.2.3 Aircraft Validation Data

Aircraft data is important to the program both before and after launch. Before launch, it provides the means to demonstrate expected product performance and to establish algorithm approaches that will work in the presence of actual environmental conditions. After launch, it is a major part of system validation. The NAST, Scanning HIS, MAS, PSR, APMIR, MASTER and AVIRIS aircraft instruments are key components for performing product validation.

1.2.4 Other Sensors Validation Data

Similarly, data from precursor sensors are used to test algorithms in the pre-launch phase and to validate the data products from the NPP sensors. MODIS serves as the source of test data for VIIRS algorithms. AIRS will serve as the source of test data for CrIS while AMSU/HSB will serve as the source for ATMS. Validation will be done against these sensors plus OLS and AVHRR for VIIRS and HIRS/AMSU and possibly IASI/AMSU for CrIS/ATMS.

1.2.5 Coordinated Measurement Campaigns

It is important for the Government Team to plan for the necessary data gathering and data analysis which can suggest instrument processing adjustments and algorithm evolution that will foster the maximum utilization of NPP data. This will be an intensive effort after CrIS, VIIRS, and ATMS launch on NPP and continue throughout the life of NPP and after that through the NPOESS Era.

IPO and NASA began conducting missions with the NAST, S-HIS, and MAS instruments in 1997 and will continue such missions throughout the remainder of this decade. Significant missions already conducted include the SAFARI mission at EOS sites in South Africa, and a joint water vapor experiment with the DOE centered around the Atmospheric Radiation Measurement (ARM) site in Oklahoma. NOAA has been and will continue to conduct Calibration/Validation of the operational polar orbiting visible and infrared imagers and the infrared and microwave sounders throughout the decade; DoD has been and will continue to conduct Calibration/Validation of the operational polar orbiting microwave imagers and sounders and visible/infrared imagers throughout the decade; inter-calibration of the ongoing series of POES and DMSP sensors and the associated sounding and imaging products is a high priority for these efforts.

Major expenses such as ship and aircraft deployments and other field campaigns will be jointly funded and managed. In addition, many of these activities will benefit from other agency programs. Key among those are the ongoing activities of the ARM-CART program of DOE, the LTER program of NSF, the operational Calibration/Validation programs of NOAA, DoD and IPO, and programs such as NASA's AERONET and MOBY future field campaigns.

1.2.6 Data Processing

NPP data will be processed at two facilities: 1. Interface Data Processing Segment (IDPS), requiring operational capabilities; and 2. Science Data Segment (SDS) for climate research purposes.

IDPS (Operational Processing)

The data from NPP instruments will be processed by the Interface Data Processing Segment (IDPS) and delivered to the users at the operational facilities in the form of Raw Data Records (RDRs), Sensor Data Records (SDRs), and Environmental Data Records (EDRs). Participants in the IPO Calibration/Validation Team will have access to these data either from direct broadcast, from arrangements with the operational facilities at NESDIS and AFWA, or from the NOAA Long term Archive.

SDS (Climate Research Processing)

The NASA Science Data Segment (SDS) will provide a production facility with reprocessing capabilities of NPP data, using algorithms developed by the GCST. Their data products are identified as Level 1B and Climate Data Records (CDRs) since they will be optimized for climate studies. The SDS will also support access to RDRs, and selected SDRs and EDRs processed at IDPS to support validation activities by the GCST teams. The SDS will maintain a store of all mission data for the life of the mission, except SDRs and EDRs.

1.3 Phasing of Activities and Evolution of This Plan

This plan is expected to evolve. The activities detailed here are already underway and they will continue through to the end of the NPP mission. Post-launch activities will peak in the year following the launch of NPP assuming full delivery of all data products is underway by launch plus six (6) months. Sustaining and intermittent Calibration/Validation activities will continue throughout the NPP mission and should overlap the first NPOESS satellite system Calibration/Validation efforts. This plan will be updated periodically.

As other government-sponsored participants are identified, this plan will be expanded to include them by incorporation of, or reference, to their independent plans. A separate plan will be developed to reflect the coordination of the government-sponsored activities with those detailed here.

The plan introduces the NPP and the instruments to be flown, describes the associated products, details pre-launch characterization and calibration efforts using NIST traceability, lists the validation approaches for the level 1 and 2 products (including ancillary data from ground based, airborne, and other satellite systems), and recommends data processing support necessary for quality assessment. Appendices include Environmental Data Record (EDR) performance requirements, lists of characterization and calibration tests, summaries of field experiments and ground networks involved in the NPP Cal/Val, and various science supporting references.

In summary, the NPP Cal/Val Plan:

* Identifies efforts necessary for verification of pre-launch and post-launch instrument characterization and calibration.

* Defines NPP products (CDRs will be defined after NRA selection), as well as the testing and evaluation necessary to ensure product quality.

* Defines validation approaches and validation data sets

* Identifies types of field experiments that will be needed to support NPP Cal/Val efforts as well as NOAA and DoD familiarization, product development, and test with advanced NWP models.

* Identifies procedures for user evaluation and feedback.

* Identifies the necessary linkages between NOAA, DoD and NASA organizational elements using NPP data, products (RDRs, SDRs, EDRs and CDRs), and services

* Provides a product management structure for the Government Team, stresses linkages to the NESDIS Product Oversight Panels and the DoD Product Panels, and identifies the need for the multi-agency technical advisory committee, the IPO Integrated Product Team (IPT).

* Identifies resources that are needed to carry out this plan.

2 Introduction

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is a joint DOC/NOAA, DoD and NASA program merging the current POES & DMSP systems into a common system of polar satellites with the goal of providing meteorological, atmospheric, oceanographic, terrestrial, climate, space environment and other environmental data products operationally.

In order to achieve these goals, these programs must produce accurate and precise long-time series of radiometric measurement data from multiple instruments on multiple platforms. Understanding and correctly interpreting these data require the ability to separate geophysical variability from instrument response changes in the observed signal during the missions. This requires a detailed pre-launch, system-level instrument characterization, as well as extensive in-flight calibration and validation activities.

The NPP defines a program to implement and demonstrate a satellite platform, proto-flight instruments, ground data system, command and control system, and algorithms for EDRs and CDRs. It is a bridge between NASA EOS era science measurements and the start of NPOESS full operational capabilities. NPP provides a linkage between EOS instrumentation and the NPOESS series of instruments. NPP strives to use equipment and procedures developed for EOS instrumentation and POES/DMSP instrumentation for both pre-launch and post-launch testing.

NPP is a joint agency program. The Table 2-1 and Figure 2-1 show in words and graphics the division of responsibilities between IPO and NASA.

Table 2-1: NPP Division of Responsibilities between IPO and NASA

IPO

- Joint Program Management
- VIIRS Instrument/Algorithms
- CrIS Instrument/Algorithms
- Command, Communications, and Control Segment
- Interface Data Processing Segment – for RDR, SDR and EDR Production
- Mission Management and Satellite Operations
- Manage NPP cal/val of RDRs, SDRs and EDRs
- Science Support (IGS)

NASA

- Joint Program Management
- Mission System Engineering, Integration and Test
- ATMS Instrument/Algorithms
- Spacecraft and Subsystem/instrument Integration to the S/C
- Launch Vehicle and Associated Activities
- Science Data Segment – for Global Change Science Initiative
- Manage NPP cal/val of Level 1B and CDRs
- Science Support (NRA)

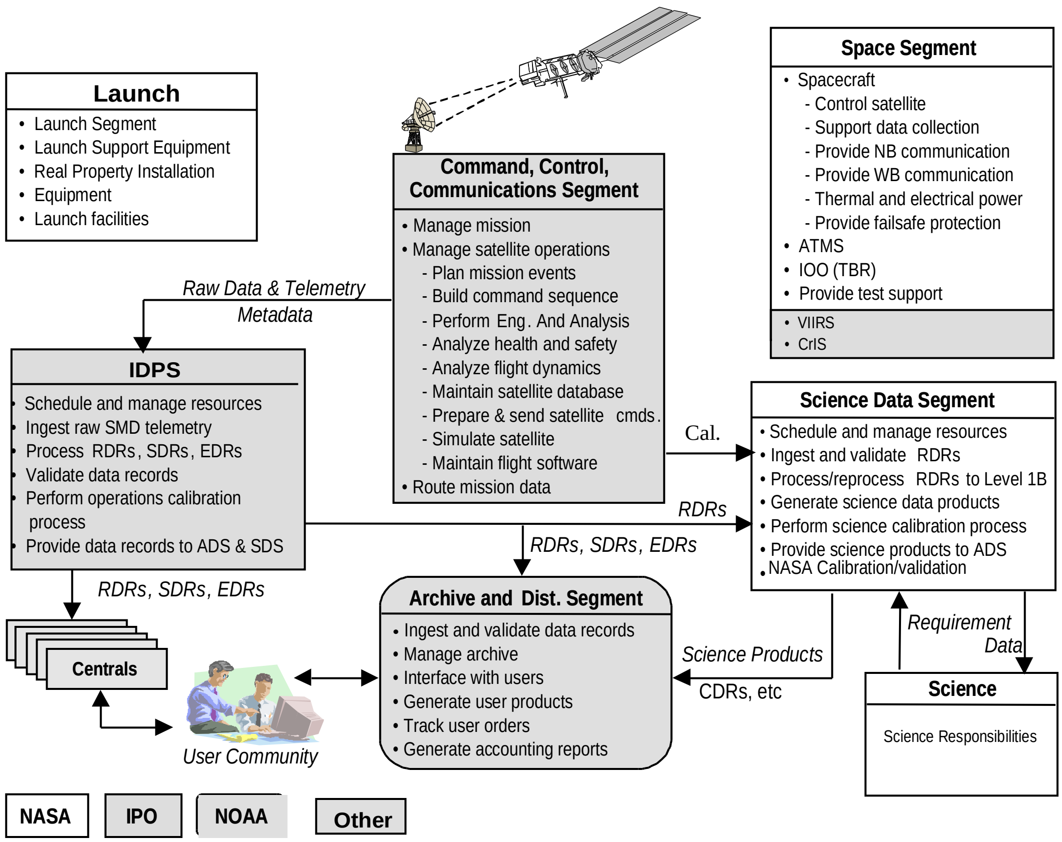

Figure 2-1: Agency Responsibility for NPP Segments and Data Flow

A description of NPP and NPOESS missions may be found at:

> http://jointmission.gsfc.nasa.gov/
> http://npoesslib.ipo.noaa.gov

This NPP Calibration and Product Validation Plan document provides a roadmap for the validation of Level 1A and 1B Products, RDRs and SDRs (calibrated/navigated radiances) and Level 2 and higher Products (EDRs and CDRs). The general strategy and specific implementation plans for validating VIIRS and CrIMSS products are presented. CrIMSS, the Cross-track Infrared/Microwave Sounding Suite is the combination of the key component instruments, CrIS, and ATMS.

The elements of NPP Cal / Val Plan include:

- Pre-launch participation, consultation, and recommendation regarding instrument design, test plans, and performance verification
- Participation in the formal review processes
- Contribution to post-launch instrument characterization and trending analysis
- Timely access to test data and access to instrument contractor calibration algorithms
- Development of research quality Level 1 products and validation during the mission
- Support of calibration and validation of instrument radiance (Level 1, RDRs and SDRs), EDRs and CDRs.
- Coordination within the IPO (DOC/NOAA, DoD and NASA) and with the external scientific community to assess the use of research algorithms in the operational system to produce EDRs with improved geophysical parameters.

2.1 Bridging the EOS and NPOESS Eras

2.1.1 Maintaining Continuity of Data Records

NPP sustains some of the measurement series initiated under the EOS Terra and Aqua missions and the POES/DMSP missions. These measurement series are being considered for continuation operationally in the NPOESS missions. As such it is essential that direct comparisons be made between EOS and NPP instruments. Furthermore, MODIS and VIIRS, CrIS and AIRS, and ATMS and AMSU/HSB should have a minimum of six months overlap in operations (i.e., after activation of instruments) to assure that at least some aspects of seasonal variation are characterized.

2.1.2 NPP Bridging Mission

This NPP Calibration/Validation plan defines the government team contribution to a combined government-contractor effort to verify NPP sensor and algorithm performance pre-launch and details NPP test activities directed at evaluation and verification of NPP products post-launch. The NPP Calibration/Validation must satisfy both IPO (Operational System) and NASA EOS (Climate Change Research) requirements. The IPO and NASA requirements have been combined in this joint NPP plan. To clarify between operational and climate research products, distinctive names were chosen; the IPO RDR product corresponds to what NASA characterizes as Level 1A product; the IPO SDR to NASA Level 1B product, and the IPO EDR to NASA CDR or Level 2 product (Table 2.2). IPO RDRs, SDRs and EDRs are produced at the IDPS, and NASA Level 1A, Level 1B and CDRs are produced at SDS. Coordination within the IPO, NASA and with the external scientific community will be conducted to assess the use of research algorithms in the operational system to produce EDRs with improved geophysical parameters.

Table 2-1: Data Set Processing Levels

Data Level: NASA	**IPO**	**Description**
Level 1A: High quality research products derived at SDS	RDRs: High quality operational products derived at IDPS	Reconstructed, unprocessed instrument or payload data at full resolution, time referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and geo-referencing parameters (i.e. platform ephemeris and orientation) computed and appended but not applied to the level 0 data
Level 1B: High quality research products derived at SDS	SDRs: High quality operational products derived at IDPS	Level 1A data that have been processed to sensor units.
Level 2, CDRs: High quality research products derived at SDS	EDRs: High quality operational products derived at IDPS	Geophysical variables derived at the same resolution and location as the Level 1 source data

Remote sensing of the earth now has science records that represent decades of continuous observation of the atmosphere, oceans, and land. A common objective of NASA and the IPO for NPP is to provide a continuation of this long-term data record. NPP/NASA science team supports the development of research quality algorithms consistent with continuation of the Earth Science Enterprise (ESE) objectives. The advanced instrumentation of NPP offers new opportunities for remote sensing research and innovations in data analysis and information extraction. In addition, NPP science is a bridge between EOS research and the science that will be supported by NPOESS. Data continuity of EOS era instruments requires that the NPP instruments be calibrated following EOS-type approaches and cross-calibration on-orbit with the corresponding EOS instruments. The objective is to establish a multi-decade data record.

To facilitate these calibration algorithm development and validation efforts, certain enabling activities have been initiated under programs such as EOS (e.g., MODIS), Sea-viewing Wide Field-of-View Sensor (SeaWiFS), and the Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS). For example, in the area of ocean color, these activities include the development of the Marine Optical Buoy (MOBY), coastal and island site augmentations of the Aerosol Robotic Network (AERONET), calibration round-robins, bio-optical and atmospheric field data archives, in situ measurement protocol development and evaluation, and field instrument technology assessment. Experience gained during these programs demonstrated that these activities are essential for establishing algorithms that meet the science accuracy requirements, post-launch validation, and on-orbit sensor performance evaluation.

NPP will be implemented in a joint program environment that provides opportunities for the participation of the research community. The VIIRS, CrIS and ATMS instrument contractors have responsibility for instrument development and performance verification, and EDR algorithm development and validation. SDR algorithms are being developed by the ATMS instrument contractor. The ATMS SDR products will be used by the CrIS contractor with the CrIS SDRs to develop the combined CrIMMS sounding EDRs. In addition, the IPO will select a Shared System Performance Responsibility (SSPR) contractor who will oversee and manage NPP instrument design and fabrication, including instrument characterization and calibration, and EDR product validation.

The Government Team will participate in this characterization and calibration and the validation of products. This joint plan addresses the validation components of that work, as well as the calibration and validation activities related to sensor design, fabrication, and test, plus the validation of the algorithms.

The NASA and IPO science teams both have an interest in insuring high quality products that will support the NASA and NOAA climate missions. High quality research Level 1B and CDR products will be generated to support the NASA research climate mission and high quality EDRs, SDRs and EDRs will be generated to support the NOAA operational climate mission.

In order to provide the calibration and operational product validation the IPO will continue to support some of the present IPO science team for calibration/validation and open the team to new investigators at least two years prior to the NPP planned launch.

NASA's selection of EDRs for validation will support Level 1B and CDR algorithm development, and seeks the reduction of the uncertainties for selected EDRs. Prior to the launch of NPP, NASA will invite the research community by a NASA Research Announcement (NRA) to propose investigations for developing state-of-the-art algorithms for CDRs and to validate selected EDRs on behalf of the global change research program.
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2.1.3 NASA Project Science Office (PSO)

The NASA Project Science Office (PSO) will represent the NASA research community in their effort to contribute to the development of NPP instruments that bridge EOS measurements into the NPOESS era through Level 1B and CDR research and development. The PSO will identify and analyze the feasible approaches for ensuring the calibration of NPP instruments to the same scale and/or cross-calibrated with the corresponding EOS instruments. The PSO will help to define the capabilities of the Science Data Segment (see Figure 2-1) and will provide guidance and recommendations to the requirements and design based on interaction with the Investigators' Teams and the larger climate research community.

The PSO works with the Science Data Segment (SDS) on product planning and reprocessing, and approves the calibration Look-Up-Tables (LUTs) updates, derived by the SDS Climate Calibration System (CCS). The PSO provides ongoing operations support, including recommendation for calibration table changes, reprocessing requests, and satellite operations planning via the SDS.

2.1.4 Integrated Program Office (IPO)

The Integrated Program Office will manage the calibration and validation of the RDR, SDR and EDR products for the operational meteorological, atmospheric, oceanographic, terrestrial and climate missions. The IPO will coordinate the government science and operational user community in their effort to assist the vendors in developing and testing the NPP instruments and to independently validate the performance of the instruments and assess the utility of the products. This will involve science team activities within the IPO Internal Government Studies and the IPO Operational Algorithm Teams. The IPO will help to define the capabilities of the Interface Data Processing Segment (see Figure 2-1) which will produce the RDR, SDR and EDR Products and the IPO will oversee the command, control, and communications and the Mission Management Center for the NPP.

2.2 Overview of NPP Sensors

The data from the three NPP instruments, VIIRS, CrIS and ATMS, will be processed in the IDPS and will be available to the SDS, ADS and users in the form of Raw Data Records (RDRs), Sensor Data Records (SDRs), and Environmental Data Records (EDRs). A brief description of each instrument/sensor is provided below.

2.2.1 VIIRS

The Visible Infrared Imaging Radiometer Suite (VIIRS) features a modular design with 22 spectral bands between 0.4 and 12 microns, nadir resolution of 370 or 740 meters (depending on spectral band), advanced focal plane detector technology, mature visible and infrared calibration systems, three stage passive radiative cooler, and heritage careful risk reduction measures; it represents a significant advance in operational polar orbiting imagers. VIIRS will be capable of producing enhanced products that include (a) cloud detection, (b) aerosol concentration and optical properties during the day, (c) cloud optical thickness, cloud thermodynamic phase, and cloud top temperature, (d) vegetation and land surface cover, (f) snow and sea-ice cover, (g) sea, land and ice surface temperature, (h) ocean leaving spectral radiances and color, (i) chlorophyll concentration, and (j) high-quality, moderate resolution imagery. VIIRS provides primary measurements for a variety of other geophysical parameters as listed in the Integrated Operational Requirements Document (IORD).

2.2.2 CrIS

The Cross track Infrared Sounder (CrIS) is a Michelson interferometer infrared sounder that is designed to measure with high resolution and high spectral accuracy the emission of infrared radiation from the atmosphere in three bands in the spectral range from 3.9 to 15.4 microns (650 – 2550 cm^{-1}). The core of the instrument is a Fourier transform spectrometer that measures in one sweep the spectral features of the atmosphere with high spectral resolution and throughput. The spectrometer transforms the incoming spectral radiance, i.e. the spectrum, into a modulated signal, the interferogram, where all infrared wavenumbers in the band of interest are present. The output from the spectrometer consists of one interferogram for each observed scene. The CrIS instrument observes the ground with an Instantaneous Field Of View (FOV) of 14 km at nadir from an altitude of 833 km. The Field Of Regard is composed of 3x3 FOVs (each FOV is simultaneously observed by a separate detector). The CrIS sensor provides cross-track measurements of scene radiance to permit the calculation of the vertical distribution of temperature and moisture in the Earth's atmosphere. It also provides supporting measurements for a variety of other geophysical parameters as listed in the IORD. CrIS data will be analyzed together with that of the collocated microwave cross-track sounder, ATMS.

2.2.3 ATMS

The Advanced Technology Microwave Sounder (ATMS) has 22 spectral channels, including windows near 23, 31, 89, 166 GHz, and several channels within the 50-60 GHz oxygen band and across the 183 GHz water vapor absorption line (13 and 5 channels respectively). ATMS has more tropospheric channels and scans more widely (no equatorial gaps between orbits) than its predecessor, the Advance Microwave Sounder Unit-A (AMSU-A) and the AMSU-B (or either of the nearly equivalent Microwave Humidity Sounder (MHS) and Humidity Sounder Brazil (HSB) instruments). The ATMS nadir resolution is 33 km for the 50-60 GHz oxygen band, and 15 km for all channels above 150 GHz, thus enhancing hurricane, humidity, and precipitation monitoring. All channels are sampled on a 15-km grid down-track and (near nadir) at 7.5 km cross-track, permitting the 77-km nadir resolution of the 23.8- and 32.4-GHz channels to be sharpened to the equivalent of ~50-km resolution, and the 33-km of the 50-GHz channels to be sharpened to the equivalent of ~25-km resolution.

2.3 Overview of Calibration/Validation Efforts

NPP provides an opportunity to validate approximately 27of the 55 EDRs to be provided operationally by NPOESS. The NPP validation program should ensure that those EDRs, and their associated algorithms, are (1) robust over all expected environmental conditions, and (2) provide values of known certainty, before the first launch of the mid-morning NPOESS satellite.

In order to validate NPP data products, it is necessary to validate atmospheric, land, and ocean parameters under a wide variety of atmospheric conditions, solar illuminations, viewing angles, and ecosystems worldwide. The Government Team will use several validation techniques to develop uncertainty information on its products. These include:

(i) Analysis of pre-launch instrument characterization and calibration data,
(ii) Coordination and collocation with higher resolution aircraft data,
(iii) Intercomparisons with ground-based and aircraft in-situ observations,
(iv) Intercomparisons with other space-based instruments, (e.g., MODIS, ASTER, MISR, AIRS, IASI, GIFTS, AMSU, HSB, MHS, SSMI, SSMIS, AMSR, GLI, AATSR, MERIS)
(v) Intercomparison with model data (e.g., NCEP, ECMWF,…)
(vi) Analysis of trends over time and consistency across boundaries (e.g., land versus ocean, day versus night, seasonal variation).

The NPP (VIIRS, CrIS, and ATMS) calibration and product validation plans and efforts benefit greatly from the validation efforts and infrastructure of several existing programs. These include the NASA EOS AIRS/AMSU/HSB, MODI S and ASTER programs, the NPOESS Calibration/Validation Program including the NPOESS Airborne Sounder Testbed (NAST) project, the DoD SSMI and SSMIS programs, the DOE Atmospheric Radiation Measurement (ARM) program, the NASA New Millennium Program Earth Observing 3 (NMP EO-3) Geostationary Imaging Fourier Transform Spectrometer (GIFTS), the NOAA Advanced Baseline Sounder (ABS) program for the Geostationary Operational Environmental Satellite (GOES), and the EUMETSAT METOP program introducing the Infrared Atmospheric Sounding Interferometer (IASI). Where applicable and possible, the NPP validation efforts will draw from these existing programs.

While the infrastructures for many of these programs are, or will be, in place for NPP calibration and product validation, additional resources may be required for implementation and analysis of the validation. Specifically, arrangement and funding of aircraft campaigns involving the NAST-I, S-HIS, NAST-M, PSR, APMIR, WINDRAD, MAS, and/or LASE and other special field campaigns (DOE ARM CART site, EOS sites, Polar AERI, and ship cruises) are required.

For the VIIRS, the pre-launch calibration efforts and the post-launch validation will be largely based on the MODIS, as well as AVHRR and OLS experiences. Detailed characterization of a number of sensor properties e.g., spectral response characterization, polarization, response versus scan (RVS), detector linearity, blackbody calibration, radiance determination and other sensor issues will be studied and compared to reference data. Reflective and emissive band calibrations will rely on on-board calibration systems, which are based on the solar diffuser and blackbody references. Also, lunar calibrations as it has been successfully demonstrated with SeaWiFS will provide additional verification of sensor degradation trends. On-orbit vicarious calibration, will require ground based time series such as those from MOBY and EOS calibration sites. Independent product verification using aircraft instruments, ocean cruises, and special field experiments with the MAS, NAST-I and S-HIS instruments will be needed. Finally, intercomparisons with MODIS, GLI, AVHRR, OLS, MERIS and other sensors will be performed to establish the data consistency among simultaneous
For the CrIS, the pre-launch calibration efforts and the post-launch validation will be largely based on the AIRS, HIRS, NAST, and S-HIS experiences. However, the understanding and characterization of the portion of the process of producing SDRs from

RDRs for the CrIS which is an FTIR type instrument will use mainly the FTIR instrument experiences for NAST-I, S-HIS and possibly IASI. This is due to the fundamentally different method of measuring infrared radiant energy with an FTIR system such as CrIS rather than with a grating spectrometer such as AIRS. Detector linearity, truncation due to finite dynamic range, analog-to-digital conversion, modulation of the interferogram due to scan noise, and other potential error sources will be characterized and the corresponding algorithm considerations must be incorporated. Determination of blackbody reference radiance data will be studied. Intercomparisons with AIRS, GIFTS, and IASI are planned, and aircraft campaigns with the NAST-I and S-HIS. Radiosonde, dropsonde, and driftsonde data will play a significant role in the product evaluations.

For ATMS, the pre-launch calibration and post-launch validation efforts will be similar to those detailed for AMSU in the AIRS/AMSU calibration validation plan. This is sensible because the two instruments are so similar in frequency coverage and other specifications. Thus the Cal/Val plan for NPP/ATMS is similar to those prepared by NOAA for POES, and by NASA for AMSU/HSB on Aqua. The principal calibration standards will be derived from microwave radiances predicted from (1) CrIS on NPP, (2) RAOBs in clear still air, (3) underflying high altitude microwave sensors such as NAST-M and/or PSR, and (4) microwave spectrometers on other satellites, such as AMSU on NOAA-15 and NOAA-16.

2.3.1 Pre-launch Test Data

Pre-launch instrument characterization will be the responsibility of the instrument vendors for the NPP. The Government Team team will work closely with the vendors during the pre-launch testing and characterization to assure that the post-launch instrument performance is understood and radiances are correctly assimilated (See Section 4 for details on this effort).

Necessary Resources

The validation of NPP measurements will require utilization of data from many resources, some of which are supported by agencies or countries outside of the NPP domain. Some of the resources are extant now, but may not be at the time they will be needed for the NPP activities; thus it is incumbent on the Government Team to endeavor to ensure the continued existence of these vital assets in the NPP era. In addition to the sensors and instrument networks, there is also the need to nurture the expertise in the scientific community required to make the appropriate contributions to the validation exercise.

NIST Traceability

The ability to trace the validation data to appropriate national measurement standards is of fundamental importance to the validation campaign. In addition to the primary NIST reference standards, there are others that are recognized secondary standards, traceable to NIST, that are used to calibrate sensors used in the field. These include the Spherical Integrating Spheres at GSFC, for calibrating visible radiometers, and the Water-Bath Black Body Calibration Targets at RSMAS-University of Miami (www.rsmas.miami.edu/ir2001) and at APL-University of Washington for calibrating infrared radiometers. Secondary standard thermometers are also in use at these laboratories, and elsewhere, such as SSEC-University of Wisconsin-Madison.

2.3.2 Ground Validation Network

In order to validate global atmospheric and surface properties derived from NPP satellite data, a reasonable sampling of the global variability of these products is necessary. Given that each NPP product may vary widely in space and time, most of the difficulty in validating the global products arises from limited sampling of the range of values encountered in each product. Hence, the NPP validation strategy includes not only focussed field campaigns in specific locations and under specific environmental conditions, but also a long time-series of selected measurements from a select distribution of ground validation sites. The primary surface validation sites promoted for use by NPP are those currently also being used by EOS, POES and DMSP. This enables continuity in the validation data used to assess both the EOS and NPP products. Required site/network instrumentation and measurements are specific to each discipline (atmosphere, land, ocean, cryosphere, clouds, and aerosols). Such networks include, for example, AERONET, the ARM CART sites, the EOS Land Validation Core sites, the international radiosonde network, and the MOBY sites. Additional information regarding the ground validation sites is given later in this section and in Appendix G.

2.3.3 Field Experiments

To supplement the routine observations taken at the various surface sites and to extend the range of observation variability, the NPP validation will benefit from additional key observations collected during intermittent field campaigns. These campaigns can take many forms and include both pre- and post-launch experiments, aimed at both algorithm and product validation. As with many recent campaigns, most of the experiments should be conducted in the context of larger science objectives, while also leveraging the campaign for NPP satellite validation. The experiments should provide a larger geographical extent to the routine, on-going observations made at the surface networks, and also cover a larger range of conditions (surface types, temperature, moisture, air mass, clouds, etc…) not observed at the routine sites. Other experiments with specific, targeted validation goals are also envisioned. These campaigns will often involve high altitude aircraft based sensors, as well as profiling aircraft, ship based cruises, and additional surface based sensors. The IPO developed NAST suite of aircraft sensors and similar sensors including S-HIS and MAS (for example) which provide NPP-like radiometric observations, will be used. These and other remote passive sensing, active sensing, and in-situ observations can provide the proper spatial and temporal context needed for satellite validation. The higher spectral and spatial resolution data can be averaged spectrally and spatially to simulate NPP measurements during overpass events. Some additional information on field campaigns is given in Appendix G.

2.3.4 Intercomparison with Other Satellite Sensors

A significant part of the NPP Cal/Val effort will involve intercomparison of radiances and derived products with EOS, POES, DMSP, METOP, ENVISAT, GOES, EO-3 and other available satellite sensors. Maintenance of long-term data sets and continuity of data quality is a mandate for the EOS-NPP-NPOESS series of sensors. These intercomparisons are necessary both for Calibration/Validation efforts and climate studies (See Appendix A for outlines of many of these intercomparisons using NPP validation sites).

Advanced polar and geostationary satellites likely to be in orbit during the NPP mission (e.g., METOP, ESSPs, EO-3, ENVISAT, etc.) will carry sensors with comparable, or better, spectral and spatial resolution to those sensors to be carried on the NPP. The products of these sensors will provide an important cross-validation of the NPP geophysical products. This is particularly important with regard to METOP and EO-3; products from these platforms and their operational successors are intended for use in combination with NPOESS products to provide a global high spatial and temporal resolution data set for climate research and operational weather forecast applications.

Well-characterized products of operational satellites (e.g., POES, GOES, and Meteosat) will also provide valuable satellite cross validation data.

2.4 Getting Ready for NPP

2.4.1 NPP Calibration and Validation Program Management

Key to the NPP validation program will be a management structure to ensure appropriate pre-flight instrument testing and characterization, verification of calibration approaches and values, monitoring and assessment of EDRs and intermediate products over the range of expected conditions, independent measurement and comparison of EDR and intermediate product values, and an approach for reporting and mediating discrepancies, errors and biases. Given the high cost of global product validation, NPP Cal/Val program management must also identify key community resources (e.g., marine buoy programs, EOS validation sites, ARM CART sites) required for NPP validation. In some cases, the management office must advocate and perhaps negotiate continuity of such resources.

The NPP Cal/Val program management should provide additional resources that may be required for implementation and analysis of the calibration validation effort. Specifically, arrangement and funding of field campaigns or ocean cruises experiments, involving ground instruments and/or aircraft should be coordinated.

The NPP Cal/Val program management should develop and actively manage a team of investigators to meet its goals. Clearly, the team must include a wide range of expertise. Participating agencies, or other groups or institutions (e.g., CEOS), may choose to conduct NPP validation activities. In such cases, the NPP Cal/Val program management must strive to make such efforts compatible and complementary to activities of the Government Team.

The Government Team must interact with the SSPR contractor, ideally including the algorithm developers. Such interaction may minimally include SSPR review or observations of government field campaigns or monitoring networks to identify missing measurements or inappropriate approaches, and regular workshops to reveal and discuss government results and remediation strategies, and open access to SSPR monitoring results and government-procured field, network and satellite data.

2.4.2 Calibration and Validation Team Responsibilities

In order to validate NPP data products, it is necessary to validate atmospheric, land, and ocean parameters under a wide variety of atmospheric conditions, solar illumination and viewing angles, and over a wide variety of ecosystems worldwide. The Government Team will use a wide variety of validation techniques to develop uncertainty information on its products.

2.4.3 Timeline of Major Activities

To be added

2.4.4 Participants

To be added

3 NPP Product Summary

The NPP mission provides remotely sensed land, ocean and atmospheric measurements that support research into long-term change in the global climate and serves as a risk reduction precursor for the NPOESS.

The NPP operational products, RDRs, SDRs and EDRs, for VIIRS, CrIS and ATMS will be produced using the Interface Data Processing Segment (IDPS) resources. Research algorithm Level 1, Level 2 (CDRs) and higher products will be produced at the Science Data Segment (SDS). More detail on the data processing and product generation is provided in section 7 of this document.

Level 1A (RDR) and Level 1B (SDR) products are used in three ways:

> (1) They are processed to produce products of Level 2 and higher (EDRs and CDRs), and are also used in diagnosing defects in those higher-level products.
> (2) They are used directly in some approaches to numerical weather forecasting. The weather forecasting community expects improved forecasts to result from directly assimilating radiances whenever possible instead of assimilating profiles produced using the atmospheric inversion processes. The direct assimilation of radiances can take into account all the other meteorological observations over a larger area being assimilated in the specification of the atmospheric state variable.
> (3) They contribute to a permanent archive of Level 1 products to be used for climate and engineering applications requiring the direct use of radiances, including system design (DoD, NASA, NOAA) and backgrounds (DoD). The Level 1A (RDR) archive also enables retrospective reprocessing, to improve the products of Levels 1B (SDR) and higher.

3.1 NPP Product Generation

3.1.1 IDPS Operational Products

The Interface Data Processing Segment (IDPS) receives raw instrument data and telemetry from ground stations supporting the NPP mission. The IDPS removes Raw Data Records (RDRs) from the data stream, then processes RDRs into Sensor Data Records (SDRs) and ultimately Environmental Data Records (EDRs). During the NPP era, the IDPS will supply RDRs, SDRs and EDRs to two meteorological Centrals for evaluation or use in environmental applications. These two Centrals are National Environmental Satellite, Data, and Information Service (NESDIS) and the Air Force Weather Agency (AFWA).

The IDPS also transmits RDRs, SDRs, and EDRs to the Archive and Distribution Segment (ADS) for archiving and access/distribution to the broader user community and forwards RDRs to the Science Data Segment (SDS). The SDS will interface with the IDPS installed in the NESDIS facility to establish the necessary data flows.

In addition, the IDPS provides routine instrument calibration and monitors the performance of data processing algorithms employed in the generation of environmental data and products.

3.1.2 SDS Climate Research Products

The SDS contains five functional elements:

1- Climate Data Management Service (CDMS),
2- Climate Calibration Service (CCS),
3- Climate Analysis and Research Service (CARS)
4- Distributed CDR Algorithm Validation Service (DCAVS)
5- Climate Mission Storage (CMS)

The SDS receives RDRs from the IDPS and employs algorithms sponsored by NASA to create Level 1A/B data from RDRs. The SDS provides Level 1A and Level 1B data to a small, competitively selected Science Team, the members of which are responsible for generating Level 2/3 science products called Climate Data Records (CDRs). Because the SDS stores RDRs over the life of the NPP mission and beyond, the SDS can reprocess RDRs and subsequently regenerate CDRs. The SDS forwards Level 1B data and CDRs to the ADS.

The SDS also generates and distributes science-quality instrument calibration parameters internally for application in SDS processing and externally for consideration and potential application in IDPS processing.

3.2 Description of SDRs/Level 1B Products

VIIRS, CrIS and ATMS Sensor Data Records (SDRs) are full resolution sensor data that are time referenced, Earth located, and calibrated by applying the ancillary information, including radiometric and geometric calibration coefficients and geo-referencing parameters such as platform ephemeris. These data are processed to sensor units (e.g., radiances). Calibration, ephemeris, and other ancillary data necessary to convert the sensor data back to sensor raw data (counts) are included.

For all NPP instruments (VIIRS, CrIS and ATMS), the operational SDR products from IDPS and Level 1B research product from SDS should, at a minimum, consist of the following information (Table 3.1):

Table 3-1: SDR/Level 1B information required for NPP sensors

Spacecraft ID tag
Sensor ID or serial number
Flight software version number
Orbit number
Beginning Julian day and time tag
Ending Julian day and time tag
Ascending Node Julian day and time tag
Spectral radiance in all channels
Signal levels from all visible detectors.
Geolocation: geodetic latitude and longitude for each sample
Time tag information – beginning of scan time
Scan index

3.3 Description of Level 2 (EDR/CDRs) Products

The NPP Mission will produce a series of Environmental Data Records (EDRs) which are a subset of the NPOESS EDRs. All 27 NPP EDRs will be produced at the IDPS and a subset of these, and potentially other products, will be produced as Climate Data Records (CDRs) at the SDS. These EDRs and CDRs may have different requirements. In the case of operational products, emphasis will be on generating products with a more rapid data delivery that necessarily involves high-speed availability of ancillary data and high-performance execution of the sensor contractors' state-of-the-art science algorithms for civilian and military applications. For climate research products, the requirement of timeliness can be relaxed, thereby allowing for the implementation of complex algorithms using diverse ancillary data. As understanding of sensor calibration issues and radiative transfer from the Earth and Atmosphere improves, algorithms can be improved, and products can be generated via reprocessing.

NPP and climate research monitoring may have different product attributes in their requirements. NPP EDRs requirements were defined by the three NPOESS agencies, NOAA, DoD and NASA considering all of their operational missions. These EDR requirements can be found in the Integrated Operational Requirements Document II (IORD II). Appendix B provides the IORD tables of requirements for each of the NPP EDRs. NPP EDRs can be broken into two categories: primary and secondary. Primary EDRs are those EDR attributes for which a sensor contractor has been assigned primary sensor and algorithm development responsibility (NPP mission will provide 4 Primary EDRs: Atmospheric Moisture and Temperature Profiles, Imagery and Sea Surface Temperature). Secondary EDRs are those EDR attributes for which the sensor may provide data as a secondary input to an EDR algorithm assigned as a primary EDR (all non-primary EDRs).

Since the CDRs will be produced by a future science team, selected by an open, peer-reviewed process through a NASA Research Announcement (NRA), CDR requirements will not be provided at this time in this document.
The NPP EDRs/CDRs can be categorized into six (6) groups, plus an Imagery EDR (Table 3-2 and Table 3-3):

(1) Atmospheric sounding,
(2) Aerosol,
(3) Cloud,
(4) Land,
(5) Ocean,
(6) Snow and ice.

Table 3-2 provides the comprehensive list of 27 EDRs and clear column radiances that will be produced in the IDPS during the NPP era. Detailed requirements for these EDRs are provided in Appendix B. Section 3.4 provides a short description of the specific requirements adopted by NPP/NPOESS for the EDR products. It should be noted that many products will be derived from a combination of radiance measurements from the CrIS, VIIRS, and ATMS. Here we note which instrument is primary in the determination of each product.

Table 3-3 provides a list of CDRs that have great potential to be selected as CDRs during the NRA process. However, other products might be included or selected during this process. This list will evolve during this document development, and will be completed after the GCST selection some time in mid-2002. Here again, most of these products will be derived from the combination of radiance measurements provided by the CrIS/VIIRS/ATMS suite of instruments.

Table 3-2: IDPS EDRs, Product Group, & Primary Associated Instruments

Name of Product	Group	Type
Imagery *	Imagery	EDR
Atmospheric Vertical Moisture Profile *	Atm. Sounding	EDR
Atmospheric Vertical Temperature Profile *	Atm. Sounding	EDR
Pressure Vertical Profile	Atm. Sounding	EDR
Clear Column Radiances	Atm. Sounding	SDR
Precipitable Water	Atmosphere	EDR
Suspended Matter	Atmosphere	EDR
Aerosol Optical Thickness	Aerosol	EDR
Aerosol Particle Size	Aerosol	EDR
Cloud Base Height	Cloud	EDR
Cloud Cover/Layers	Cloud	EDR
Cloud Effective Particle Size	Cloud	EDR
Cloud Optical Thickness/Transmittance	Cloud	EDR
Cloud Top Height	Cloud	EDR
Cloud Top Pressure	Cloud	EDR
Cloud Top Temperature	Cloud	EDR
Active Fires	Land	Application
Albedo (Surface)	Land	EDR
Land Surface Temperature	Land	EDR
Soil Moisture	Land	EDR
Surface Type	Land	EDR
Vegetation Index	Land	EDR
Sea Surface Temperature *	Ocean	EDR
Ocean Color and Chlorophyll	Ocean	EDR
Net Heat Flux	Ocean	EDR
Sea Ice Characterization	Snow and Ice	EDR
Ice Surface Temperature	Snow and Ice	EDR
Snow Cover and Depth	Snow and Ice	EDR

CrIS/ATMS VIIRS | * NPP primary EDRs

Table 3-3: Potential CDRs, Product Group, and Primary Associated Instruments

Name of Product	Group	Type
Clear Column Radiance (CrIS)	Atm. Sounding	CDR (TBD)
Ozone	Atm. Sounding	CDR (TBD)
Precipitation Rate	Atm. Sounding	CDR (TBD)
Trace Gasses	Atm. Sounding	CDR (TBD)
Cloud Ice Water Path	Cloud	CDR (TBD)
Cloud Liquid Water	Cloud	CDR (TBD)
Atmospherically Corrected Reflectance	Land	CDR (TBD)
Active Fire	Land	CDR (TBD)
LAI/FPAR	Land	CDR (TBD)
Sea Surface Temperature	Ocean	CDR (TBD)
Ocean Color (Water Leaving Radiance)	Ocean	CDR (TBD)

CrIS/ATMS VIIRS Not yet Assigned to VIIRS or CrIS/ATMS

3.4 Summary of EDRs/CDRs Performance Requirements

The NPP will produce a series of EDRs that is a subset of the NPOESS EDRs. The following environmental and climate data record (EDR/CDR) requirements define the environmental data to be derived from the NPP data stream and delivered to users to meet mission needs. EDRs and CDRs requirements are listed in the Appendix B (CDRs requirements will be available after NRA selection), including attribute thresholds which characterize satellite sensor data requirements.

EDRs requirements (Appendix B) are specified with a general definition of required data content, the units for the reported data, and a set of attributes that fall into four categories:

(1) those that further define data content in a precise, quantitative manner,
(2) those that define the quality of the data to be provided,
(3) those that define the reporting frequency for the EDR, and
(4) timeliness of EDR delivery to users.

Attributes addressing data content are:

(1) horizontal and vertical cell size,
(2) horizontal and vertical reporting interval, and
(3) horizontal and vertical coverage.

Attributes addressing data quality are:

(1) measurement uncertainty,
(2) measurement accuracy,
(3) measurement precision,
(4) long term stability, and
(5) mapping uncertainty.

All of these attributes apply to data products, not to sensor performance characteristics, and are defined in the Appendix J (Definitions). The product attributes' performance flows to the sensor and algorithm performance specifications. The EDR requirements format (Appendix B) addresses the data content attributes first, then the data quality attributes, and finally the reporting frequency attributes. The latency requirements are not applicable for the NPP.

Seven EDRs, Imagery, SST, soil moisture, cloud base height, pressure, snow cover and depth and precipitable water, are not required to satisfy the "cloudy/all weather" attribute because the required sensors are not flown on NPP (required sensors will be available for the NPOESS system). Three EDRs, aerosol optical thickness, aerosol particle size and net heat flux are not required to meet the attribute thresholds because the required sensors are not flown on NPP (required sensors will be available for the NPOESS system).

4 Instrument Pre-launch Characterization and Calibration

4.1 Common Issues for Instrument Characterization and Calibration

Characterization describes quantitatively how a system or subsystem responds under the range of conditions to be encountered in use. Calibration describes how to quantitatively convert sensor units (RDRs) to scientific units (e.g. radiances in SDRs). Characterizations are needed both for producing calibrations and for redesign and diagnostic purposes. Characterizations and calibrations must be sufficiently accurate to enable the SDR processing to produce high quality radiance-based EDRs/CDRs.

The Government Team will aid in evaluating the instrument vendor pre-launch characterization and calibration plans and performance; the Government Team will also perform independent checks of the instrument vendor measurements and analyses. The Government Team participates in the design, test, and performance verification of each of the instruments. They have timely access to test data. All data requests will be made through the respective government instrument developers in advance of test execution. The Government Team has access to instrument contractor calibration algorithms and research code. This provides a starting point for IDPS and SDS implementation of improved quality SDRs and Level 1B products. The instrument developers will enable this exchange of information. Figure 4-1 shows how characterizations and calibrations of subsystems flow into those of more complete systems.

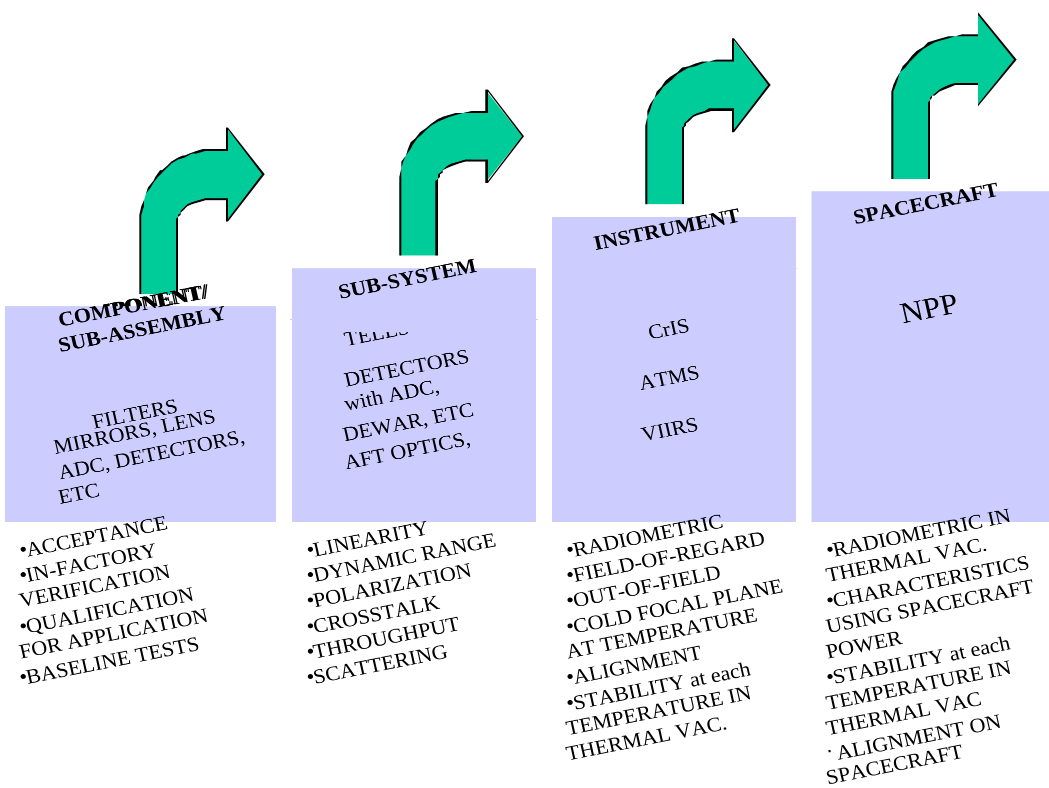

Figure 4-1: Instrument Characterization Occurs at all Levels of Assembly

The following ingredients of characterization and calibration apply to all NPP instruments:

- **Spectral response** including center wavelength or frequency, bandpass, channel location on focal plane (if applicable), out-of-band response, and spectral cross-talk.
- **Spatial response** including response to point and edge sources, pixel boundary locations (if applicable), image deformation on the focal plane (if applicable), out-of-field responses (including stray light), and alignment.
- **Radiometric response** including radiance responsivity in appropriate units, linearity, dynamic range, noise, cross-talk, and dead, marginal, and hot pixels.
- **Polarization tests** that quantify the response to polarized radiation. Even when the radiation incident on the instrument is unpolarized, reflections from spacecraft/payload surface may introduce polarization.
- **The spectral, spatial, radiometric, and polarimetric tests** should include both staring mode and scanning mode views, if applicable.
- **Analog-to-digital converters** and other electronic components critical to the spectral, spatial, radiometric, and polarimetric response should be characterized.
- **Environmental stability characterization** including response to changes in operating temperatures and spatial gradients of temperature, response to space radiation, response to saturation, and response to spacecraft power variation. Thermal vacuum testing should characterize the effect of operating temperature on spectral, spatial, and radiometric characterizations and calibrations of the instrument. Thermal performance tests shall incorporate the same spatial gradients of temperature expected on orbit.
- **On-board sources and calibration systems** (emissive and reflective targets) require characterization over the range of expected viewing angles and external illumination. BRDF and polarization should be measured, and the NIST-traceability of BRDF scales should be experimentally verified as described in Section 4.5. Radiance, spectral content, and spatial distribution function should be characterized for self-emitting sources used within instruments, including the effects of thermal expansion on the measured signals.
- **GSE test targets and sources** should be characterized fully prior to use with the instrument(s). Independent verification of source characteristics is recommended, and particularly NIST-traceability of radiance scales as established by such sources should be verified as described in Section 4.5.
- **Both ambient and thermal vacuum testing** of the instrument should be performed. Optical stimulus is to be provided and instrument response characterized while the instrument is in thermal vacuum test prior to delivery to the spacecraft. Data should be taken at coldest, intermediate, and hottest environments. Response data should be collected at the spacecraft level of assembly.

An essential part of these calibration and characterization activities is the use of instruments having accurate measurement scales. While test instrumentation used by instrument vendors is often claimed to be NIST traceable, experience with radiometric measurements indicates that an experimental verification of NIST traceability of vendor radiometric scales at economical points in the test process is necessary in order to establish confidence in the high accuracy products required by NPP. IPO has enlisted NIST assistance to perform these radiometric traceability verifications as summarized in Section 4.5 and detailed in Appendix C. The activities under the NIST traceability verification plan are cost-effective and proven from heritage on other programs.

One final aspect of the pre-launch characterization and calibration plan applicable to all instruments is the development, use, and maintenance of detailed and accurate math models. These models will be used for a variety of purposes:

- Define and iterate with systems engineering requirements and error flow-downs.
- Define critical functions for test hardware and establish tolerances.
- Review existing documentation on math models developed in support of error budgets of vendor calibration sources.
- Predict results prior to testing based on as-measured parameters.
- Analyze laboratory measurements.
- Predict sensor performance based on these measurements.
- Define calibration coefficients for the instrument database.
- Act as a resource to monitor, simulate, and troubleshoot changes in calibration once in orbit.
- Utilize for on-orbit operational purposes later in the program as appropriate.

4.2 VIIRS Pre-Launch Characterization and Calibration

VIIRS calibration involves measuring pre-launch and post-launch the response of the instrument subsystems to controlled, well-characterized stimuli. Pre-launch instrument characterization should be performed under environmental conditions (thermal vacuum tests), which simulate on-orbit conditions as closely as possible.

Absolute radiometric calibration and associated uncertainties / instabilities will be verified by analysis, modeling, and / or simulation. The process of satisfying the radiometric calibration requirements against both uniform and structured backgrounds will be accomplished through instrument characterization using NIST traceable standards. The radiance levels applied to the calibration process will be based on flow-down requirements for the EDRs based on measuring top-of-the-atmosphere radiance levels.

The characterization and calibration process will follow well-defined protocols and guidelines established within NASA, NOAA and DoD and detailed by MODIS, AVHRR, and OLS calibration and characterization teams. The VIIRS sensor calibration will incorporate onboard calibration, including Solar Diffuser (SD) and thermal blackbody. The in-flight calibration process will also include solar, deep space, and lunar radiometric calibration opportunities.

More details on VIIRS characterization and calibration are presented in Appendix D; a short summary follows.

4.2.1 VIIRS Instrument Characterization

Instrument characterization enables the determination of the quantitative effect of the performance of the subsystem on the overall instrument system-level performance. Table 4-1 presents VIIRS parameters to be characterized and calibrated, using MODIS-heritage test equipment at SBRS. It includes:

- **Radiometric Response** - At the component level of assembly, the response of focal plane elements and subassemblies are characterized for linearity, dynamic range, noise, various cross-talk sources, mirror scan angle variation (RVS), and dead and marginal performing detector channels. At the subsystem level of assembly, tests with digital electronics determine ADC characteristics and anomalies. At the instrument level of assembly, response is characterized with static and active scans. Tests include pathological target cases (cloud over ocean and littoral waters).

- **Spectral Response** - Optical element, subassembly, and instrument level spectral characterization includes center wavelength, band-pass, out-of-band response, cross-talk from other spectral regions, spurious response to near field sources (warm optical path seen by cold focal plane), signal level dependent out-of-band response, others as identified.

- **Spatial Response** - Knowledge of point source and edge response, center of pixel position, edge of pixel position, relative alignment of spectral bands each to the other during static and active scan, knowledge of the line-of-sight, variations with field-of-regard, errors at aggregation switching points, and others identified later.

- **Stability –** Changes with time and environmental conditions must be characterized. The stability of the instrument as it passes from night to day and back must be understood. The VIIRS may have a different power profile day and night; the transient associated with each must be understood.

Special care should be taken to decide which characterization test should be performed in the ambient environment or in both the ambient and thermal vacuum environments.

Table 4-1: Characterization and Calibration of the VIIRS Instrument

Test Parameter	**Test Environment**	**Optical Stimuli or Comparison Radiometer**
Radiometric Characterization & Calibration		
Linearity of the detector and repeatability	Amb Lab, T/V	Radiance level changes
Polarization	Amb Lab	Polarization Source Assembly
Signal-to-Noise Ratio	Amb Lab and T/V	Spherical Integrating Source
Dynamic Range	Amb Lab and T/V	Spherical Integrating Source, Blackbody Calibration Source
Focal Plan Temperature	T/V	Spherical Integrating Source
Spectral Response		
Relative Spectral Response	Amb Lab and T/V	Spectral Measurement Assembly
Out-of-band response	Amb Lab	Spectral Measurement Assembly
Spatial Response		
Response Versus Scan	Amb Lab	Spherical Integrating Source and Blackbody Calibration Source
MTF/point spread function	Amb Lab and T/V	Integrated Alignment Collimator
Near field scatter	Amb Lab and T/V	Scatter Calibration Measurement Assembly
Far field scatter	Amb Lab	Quartz halogen source
Ghosting	Amb Lab	Scatter Calibration Measurement Assembly
Electronic cross talk	Amb Lab	Spectral Measurement Assembly
Optical cross talk	Amb Lab	Spectral Measurement Assembly and Integrated Alignment Collimator
Pointing knowledge	Amb Lab	Integrated Alignment Collimator
Alignment change	Amb Lab	Integrated Alignment Collimator
Spectral band registration	Amb Lab and T/V	Integrated Alignment Collimator +Reticles
Stability		
Short-Term Pre-flight	Amb Lab	Spherical Integrating Source +monitoring radiometer
Short Term on-orbit	On-orbit	Solar Diffuser / Solar Diffuser Stability Monitor, Moon (experimental)
Long-term	On-orbit	Solar Diffuser / Solar Diffuser Stability Monitor, Moon (experimental)

4.2.2 On-Board Calibrator Characterization

In addition to these tests, the pre-launch and on-board calibrators should be characterized to ensure the required on-orbit calibration performance. Specifically, the BRDF of the Solar Diffuser should be analyzed, and its stability well understood. The NIST-traceability of the BRDF scale of SBRS should be experimentally verified as described in Section 4.5. The Solar Diffuser Stability Monitor (SDSM) and the Blackbody Calibrator should be characterized assuming operational conditions.

4.3 CrIS Pre-launch Characterization and Calibration

The basic radiometric and spectral performance of the CrIS over the life of the mission is the focus of these efforts. The requirements for continued long-term EDRs/CDRs puts special emphasis on production of consistent SDRs which depend on a complete understanding of the instrument radiometric, spectral, and spatial characteristics determined pre-launch. This can only be accomplished by normalization of observed radiances for all FOVs to a common wavenumber scale and instrument line shape, making the SDR product equivalent to a Level 1C product. This normalized SDR product, when performed up-front in the processing, will allow relatively inexpensive re-processing of EDR/CDRs to form consistent long-term data sets. Careful definition of the frequency scale and instrument line shape are not only important for SDR production but are also used directly in the EDR/CDR production via the forward radiative transfer model. A stable SDR is also essential for all users of CrIS, especially the numerical weather prediction centers, who directly assimilate the SDRs into their models. These users cannot cope with any significant variation in the SDR frequency scale or instrument line shape and consequently pre-launch testing must provide a detailed understanding of how these parameters could drift over time.

The fundamental approaches for prelaunch radiometric testing of the CrIS Fourier Transform Spectrometer (FTS) are similar to those for any IR radiometer, but special spectral testing and detailed analysis differences are necessary. Because profile retrievals are sensitive to characterization accuracy of the instrument spectral calibration, and because of the relatively short history of spaceborne high-spectral resolution radiometry, the importance of the spectral part of the CrIS calibration effort is emphasized. The Government Team-led effort will review CrIS vendor (ITT) test plans for completeness and will make use of test data collected by ITT. Coordinated applications of NIST sensor and source standards are also briefly addressed here.

4.3.1 CrIS Radiometric Calibration

The following general activities will be performed to confirm absolute radiometric accuracy and reproducibility.

Blackbody reference checks are mandatory. As discussed in Section 4.5, a NIST maintained FTIR transfer radiometer system (the Fourier-transform Thermal-Infrared Transfer Radiometer, FTXR) will be used to verify the radiance from the external blackbody standard used in CrIS testing. While this FTIR system may be no more accurate than the CrIS blackbody reference itself, the system will provide transfer observations for comparing the standards used for CrIS and VIIRS. Any observed differences will be explored to reduce absolute errors. The NIST radiometric calibration of the FTXR will consist of laboratory characterizations and calibrations using the NIST radiometric infrastructure described in Appendix C.

CrIS measurements of an external blackbody will be used to verify CrIS end-to-end absolute accuracy and reproducibility. The blackbody will be operated at a range of temperatures spanning atmospheric conditions and the test will be repeated over the range of instrument temperatures expected in flight. This test will be used for:

- verification of non-linearity corrections derived from separate tests (if similar tests are used, the verification needs to be from independent data),
- verification that the observed responsivity (signal level) is consistent with component level optical and detector characteristics, and
- verification of interferometric phase stability and check that the imaginary part of the calibrated spectrum is not influenced by any artifacts, except pure noise.

Any unexpected behavior must be evaluated.

4.3.2 CrIS Noise Performance Verification

The end-to-end noise performance will be evaluated by deriving the Noise Equivalent Spectral Radiance (NESR). This characterization should be performed as a function of scene temperature using the same data collected for radiometric calibration (4.3.1). Analyses to be performed include:

- determination of the NESR from all sources by taking the standard deviation of calibrated spectral radiances for a stable blackbody source and instrument,
- estimation, by separate analysis, of random noise (uncorrelated with wavenumber) and interferometric noise, and
- identification of any spectrally localized noise sources indicative of EMI.

Any significant differences from expectations should be resolved.

The noise characteristics as a function of scene temperature are required for CDR as well as EDR production, and must be provided in addition to the SDRs.

4.3.3 CrIS Spectral Calibration

CrIS spectral calibration specifies the shape of the instrument spectral line-shape and wavenumber scale. Under perfect instrument alignment, the Fourier transforms of the 9 FOVs in each focal plane will produce 3 distinct channel wavenumber scales. In addition, the instrument line-shape function spectral width will vary slowly with wavenumber. These effects arise from the fundamental linkage between spatial and spectral response in an interferometer. Fortunately, with a FTS (that ties the spectral characteristics to a reference laser and to a small number of geometrical parameters) the spectral characterization of a small number of channels per band is sufficient to calibrate all channel spectral characteristics.

The goal of spectral calibration is to (1) directly measure several CrIS instrument line shapes in each band, and (2) establish the CrIS absolute wavenumber scale. These two quantities are integrated into the EDR/CDR/assimilation forward model to allow regression of the observed radiances to computed radiances in order to retrieve the atmospheric state.

The required spectral characterization and calibration refinements can be obtained from measuring well-known gas transmittances. A nominal approach is described in Appendix E. A similar test was performed during EOS-AIRS pre-launch testing and was highly successful. Comparison of the gas transmittance spectrum with easily computed simulated spectra allows retrieval of the wavenumber scale and verification of the expected instrument line-shape function for each of the 3x3 FOVs.

4.3.4 Additional CrIS Characterization

In addition, pre-launch characterization of the CrIS instrument must address several issues, as discussed in the introduction to Section 4.1. These include (1) spatial response, (2) stability of radiances with varying instrument temperature, (3) cross-talk (which should be a very minor concern), and (4) effects of polarization on the radiometry. In addition, care should be taken to examine the CrIS interferograms for any channeling due to unwanted interference between optical elements. Since there is a connection between spectral and spatial response in a FTIR, analysis of calibration results should determine if these two calibration parameters are compatible.

Complete communication of the calibration results to users outside of the hardware vendor and SSPR is essential to the success of NPP.

4.4 ATMS Pre-Launch Characterization and Calibration

The pre-launch characterization and calibration of ATMS will rely heavily on the thermal vacuum calibration program, supplemented by more thorough measurements at ambient pressure and multiple temperatures, as discussed below. Some measurements should be performed on all flight instruments, and some only on an engineering unit or a single flight unit (see Appendix F for more details).

4.4.1 ATMS Temperature Sensitivity (NEDT)

Temperature sensitivities, referred to the antenna aperture, will be determined for all flight instruments (1) for antenna viewing 300K target, (2) under conditions similar to in-flight operation, and (3) with enough measurements so that more would not alter the results by more than 0.01K rms.

4.4.2 ATMS Bandpass Characteristics

The bandpass characteristics for each channel should be measured and documented over the extreme operational temperature range to be encountered in space; two or three temperatures would normally suffice, and thermal vacuum would normally not be required. The accuracy should be sufficient to ensure that no indicated brightness temperatures would depart by more than 0.2 K from that expected for any reasonable atmospheric profile solely as a result of incorrect or incomplete pre-launch bandpass characterization.

4.4.3 ATMS System Linearity

The amplifiers and detectors in sensitive radiometers often exhibit non-linearities that threaten calibration accuracy at antenna temperatures removed from those of the two calibration loads. Tests should be performed to ensure that such compensated non-linearities after compensation will introduce less than 0.1K calibration error under the most challenging plausible combinations of antenna (radiometric) and instrument temperature.

4.4.4 ATMS Calibration

ATMS is calibrated every scan cycle in space using cold space and an unheated blackbody load. Calibration errors in ATMS-like prior instruments have generally been dominated by: bandpass variations, non-linearities, unknown blackbody emissivities below unity, temperature gradients within the calibration blackbody, errors in blackbody temperature sensors, variations of instrument response with calibration switch position (in ATMS this is the position of the scanning mirror), and angle- and situation-dependent contributions to antenna temperature due to the Earth/space boundary, spacecraft, sun, and moon. Most of these potential error sources can be measured and compensated pre-launch using thermal vacuum calibration tests, laboratory measurements, and antenna range measurements. Each of these sources of calibration error should be measured so that uncompensated contributions to calibration error from each are less than ~0.1 K rms, a level that helps ensure cumulative errors less than ~0.5 K rms.

4.4.5 ATMS Antenna Pattern Measurements

Accurate antenna patterns are needed to (1) facilitate the image sharpening made possible by Nyquist sampling, and (2) assess and correct the scan-angle dependent sidelobe contributions to brightness temperature error. The uncompensated brightness temperature error, to the extent possible, should always be less than 0.1K. These errors are most critical for channels 52.8-58 GHz and are most serious when the sidelobes have significant amplitude and large-scale structure near the planetary limb. The patterns for at least one flight unit should be measured at least at the center frequency of each channel. The sensitivity of these antenna pattern measurements should permit accuracies of 2 dB rms at absolute antenna gains 20 dB below isotropic, which implies a dynamic range of at least 65 dB (TBR) for the narrow beams, essentially free of antenna-range-wall and surface-reflection effects. The rms accuracy of the absolute pattern measurement should otherwise generally be no worse than the less restrictive of 3 percent in absolute gain or 0.5 dB (TBR), and the rms precision should be one-fifth of that.

4.4.6 ATMS Polarization Angle Alignment

ATMS has several channels with temperature weighting functions peaking in the lower troposphere or below the surface. These measurements are affected by surface emissivity. Over oceans, the emissivity varies with view angle and polarization. ATMS measures an angle-dependent combination of vertical and horizontal polarization. A small misalignment of the polarization angle would therefore result in an asymmetric radiance across the scan lines. Thus, the Government Team needs to monitor the ATMS pre-launch calibration procedure including the polarization angle alignment. It is recommended that the angle be accurate to a few tenths of a degree (goal).

4.5 Verification of NPOESS Calibration/Validation Standards Using NIST Traceability

4.5.1 Plan Overview

This section presents a plan for making NIST-traceable verifications of the uncertainty of the radiometric reference standards that are relevant for NPP. There are two general classes of such standards: those used for calibration of the space flight instruments themselves, and those used for calibration of the instruments deployed in validation field campaigns. This plan addresses both of these. For radiance, the verification method is to deploy NIST portable transfer radiometers and sources at flight instrument calibration facilities and at validation field instrument intercomparisons. The NIST transfer radiometers are calibrated at NIST against the NIST radiance reference standards before and after deployment to each intercomparison. For reflectance, the verification method is through a round-robin in which participating laboratories, including the reflectance reference facility at NIST, measure the same set of diffuse reflectance panels and their results are intercompared. These methods follow the basic scheme that evolved from the NIST cal/val verification program with NASA EOS. The data from the intercomparisons are analyzed by NIST to determine the level of agreement, and this level of agreement is compared with the uncertainty required. Where scales agree to within the required uncertainty, the calibration standards can be said to have been verified. In cases where scales do not agree to within the required uncertainty, attempts are made to discover and correct the source of the disagreement.

There are five basic types of intercomparison activities that form the overall verification plan. These are summarized in the next section, and more detailed descriptions can be found in Appendix C. Appendix C also contains a substantial amount of material that describes the NIST radiometric measurement infrastructure as it relates to the absolute calibration of instruments used in these intercomparisons. The NIST traceable Reflectance Standards, the NIST traceable Radiance Standards, and the NIST traceable Standards under development are described.

The result of performing the activities in this plan will be continuity of measurement scales with other programs, assurance of the precision, accuracy and uncertainty of the EDRs, identification of systematic effects, and ties to a common measurement reference as maintained by NIST. Although this plan concentrates only on the NPP phase of the NPOESS program, it is planned that similar verification activities will continue for the duration of the NPOESS program.

4.5.2 Summary of the Intercomparison Activities

A summary of the plan in terms of activity type, dates, participants, and expected uncertainties, is given in Table 4-2. There are five types of intercomparison activities:

- **Type A**: BRDF round-robin of diffuser plates. This will be done once for the NPP VIIRS to verify the BRDF scale at Raytheon SBRS.

- **Type B**. Intercomparison of lamp-illuminated integrating spheres/plaques and radiometers. This will be done on a yearly basis for MAS and once for NPP VIIRS to verify the SBRS SIS spectral radiance scale at Raytheon SBRS.

- **Type C**. Chamber deployment of NIST thermal-IR spectroradiometer to view chamber calibration sources in-situ. This will be done once for NPP VIIRS to verify the BCS and SVT scales at the VIIRS calibration chamber at Raytheon SBRS, and once for NPP CrIS to verify the external calibration source blackbody at the CrIS calibration chamber at ITT.

- **Type D**. Thermal-infrared intercomparison of blackbodies and radiometers (at ambient temperature and pressure). This will be done on a yearly basis for NAST-I, S-HIS, and MAS, linked to particular field campaigns.

- **Type E**: Intercomparison with Portable Laser-Illuminated Integrating Sphere Source. This will be done once for NPP to update stray-light corrections in the MOBY spectrographs prior to use of MOBY for VIIRS ocean-color EDR validation.

More details of these types of activities are presented in Appendix C**.**

Note that the dates for the activity that involves the flight instrument calibration chambers (Type C) needs to be linked to chamber availability at Raytheon SBRS and ITT. NIST experience with this activity is that these two vendors are quite willing to cooperate and that there will be no impact on flight instrument schedule since the activity can be performed after the flight-instrument removal from the calibration chamber.

Table 4-2: Plan of the Intercomparison Activities during the NPP Pre-Launch Phase

	VIIRS	VIIRS	CrIS	MAS	MAS	NAST-I	MOBY
Type	A	C	C	B	D	D	E
Dates	FY03	FY04	FY04	FY 04, 05, 06	FY 04, 05, 06	FY 04, 05, 06	FY05
Duration	4 months	2 weeks	2 weeks	1 week	1 week	1 week	2 weeks
Participants*	1a, 2	1e, 3	1e, 4	1b, 1c, 1d, 5	1e, 1f, 5	1e,1f, 6	1g, 7
Uncertainties	1.4%	0.1 K	0.1 K	1%	0.1 K	0.1 K	<1%
Anticipated Agreement with NIST	1.5%	0.2 K	0.2 K	2%-4%	0.1 K	0.1 K	TBD

* These references are in the table 4-3 below.

Table 4-3: Participants in NIST Traceability Verification Activities

1. NIST Optical Technology Division a. BRDF measurement facility. b. Portable lamp-illuminated integrating sphere source. c. Portable Vis/NIR spectroradiometer. d. Portable SWIR spectroradiometer. e. Portable Thermal-IR FTIR spectroradiometer (FTXR). f. Portable water bath black body. g. Travelling-SIRCUS
2. VIIRS calibration personnel working on diffuser panel BRDF measurements (Raytheon SBRS Team).
3. VIIRS pre-launch radiometric chamber calibration personnel (Raytheon SBRS Team).
4. CrIS pre-launch radiometric chamber calibration personnel (ITT Team).
5. MAS radiometric calibration personnel (NASA Ames and/or NASA Goddard for reflective channels, Univ. of Wisconsin for thermal-IR).
6. NAST-I radiometric calibration personnel (NASA Langley, Univ. of Wisconsin, Utah State Univ., Lincoln Laboratory, Harvard Univ.).
7. S-HIS radiometric calibration personnel (University of Wisconsin).
8. MOBY team.
9. NPOESS IPO Shared System Performance Responsibility [SSPR] Integration Contractor Calibration/Validation oversight team (as needed).

5 Level 1 Product Post-launch Validation

Level 1 (RDR and SDR) products validation is the process of assessing by independent means the accuracy of the radiance derived from each instrument. Validation establishes the accuracy or confidence levels associated with each Level 1 algorithm over the range of scene conditions.
These Level 1 Products need to be independently validated, both because they are valuable products in their own right (for direct input to numerical models and for climate applications) and to allow their suitability for supporting level 2 products to be evaluated

Figure 5.1 illustrates some of the elements associated with the validation process.

Validation of satellite data, both on a global and a regional scale, are usually conducted in several ways using multiple (independent) measurement approaches. The methods include:

- satellite versus satellite comparison
- satellite versus aircraft under-flight comparison
- satellite versus numerical weather analysis comparison
- satellite versus in-situ ground, sun-photometer, radiosonde, buoy, and ship data comparison

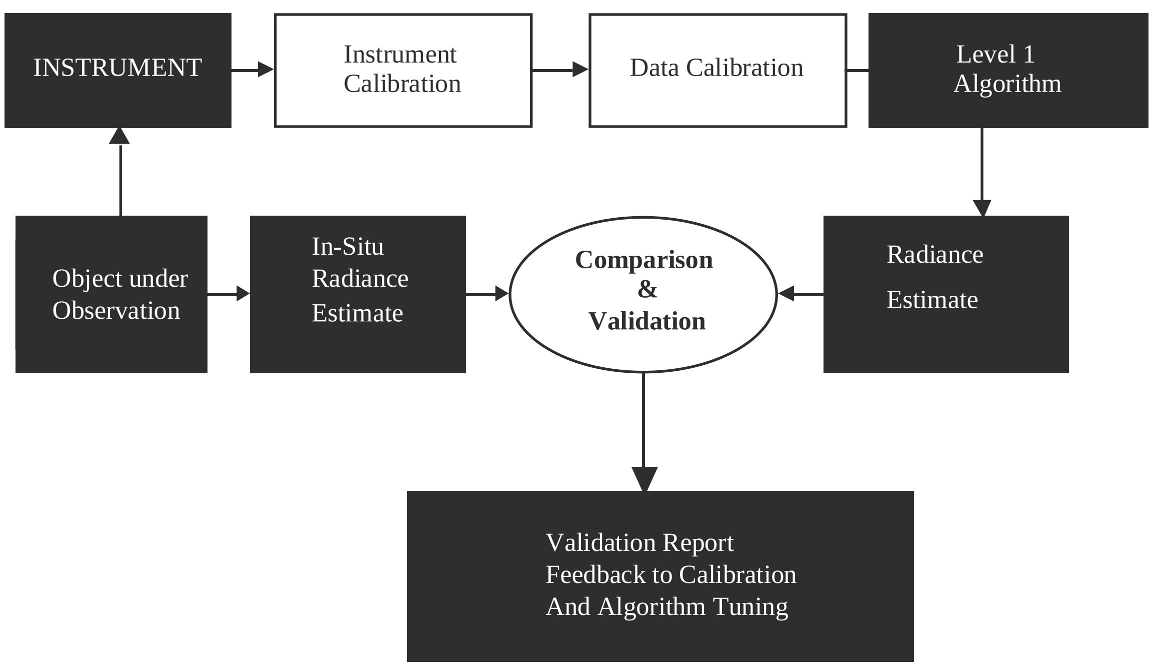

Figure 5-1: High Level Schematic of the Radiance Validation Process

Field campaigns and aircraft under-flights are resources that need to be coordinated by the Government Team with the enabling NASA and IPO authorities as well as the participating scientists.

Satellite-versus-satellite comparisons depend on overlap of orbital operations and similar equatorial crossing times. Opportunities to collect data from instruments on separate spacecraft will be identified and pursued as appropriate.

Access to radiosonde and buoy data is important. The NOAA networks allow rapid and free access to the data. Other international and national networks do not provide similar data access by external scientists. Using the non-NOAA networks for validation requires special consideration. Other resources like the NASA operated AERONET may require additional funding to acquire the data.

It is important to recognize that validation is an on-going activity/process for the mission duration including intense initial post-launch activities as well as intermittent and sustaining activities throughout the remainder of the mission.

Finally, it is important to note that for instrument/algorithm combinations designed to measure profiles rather than surfaces (that is, for sounders such as CrIS and ATMS, as contrasted to VIIRS), validation of the forward model is one of the most essential steps in the validation. The performance of current atmospheric profiling systems is typically limited by errors in the forward models rather than by the inversion algorithms (Rodgers, 2000).

5.1 Radiative Transfer Models Calculations

The two fundamentally distinct applications of forward models are (1) radiance validation, and (2) atmospheric state, cloud, and surface property retrievals.

Radiance validation will be accomplished by comparing radiative transfer model calculations using independent truth fields to the direct radiance observations. When comparing observed spectra to those calculated from independent atmospheric state data the key role of the radiative transfer model is obvious. However, radiative transfer models are also important to account for the effects of different observing altitudes and view angles for validation comparisons between satellite observed radiances and radiances observed using aircraft instruments.

For atmospheric state retrieval, the quality of the model directly affects the quality of the retrieved products. The retrieval is most often posed as the solution of an integral equation in which the kernel is provided by radiative transfer models. It is well known that this ill-posed inversion process is critically dependent on observing errors (instrument noise, spectral response uncertainties and calibration errors), and of course, forward model errors have the same effect. In fact, at this point it is undoubtedly true that forward model errors are generally larger than calibration errors.

5.1.1 VIIRS Radiative Transfer (Visible to Infrared)

The radiative transfer model used for VIIRS retrievals must accurately calculate the effects of multiple scattering in the atmosphere. This is particularly true for cloudy conditions, but the effects of aerosols under clear skies are also significant. Scattering is the dominant effect in the shortwave and absorption dominates in the longwave, but both must be considered for accurate radiance simulations. It is not sufficient to represent visible and infrared radiative transfer with no-absorption and no-scattering approximations.

The specification of cloud optical properties in forward models is therefore critical. Parameterizations of optical properties based on Mie theory are generally adequate for the representation of scattering in liquid clouds. However, Mie theory is not appropriate for ice clouds, and existing broadband models for hexagonal crystals have limited applicability. Parameterizations of the optical properties for a variety of particle "habits" have recently been developed for the shortwave and are now being incorporated into radiative transfer models. Parameterizations for the longwave need to be developed.

Even with improved cloud optical property parameterizations, however, cloud property retrievals will still suffer from the lack of a priori information on particle shape and vertical distribution. It is not likely that satellite data alone can be used to obtain information on particle shape, size, vertical distribution, and optical thickness, though some possibilities are being explored. Aircraft measurements of cloud microphysical and bulk optical properties are needed for the validation of forward models and satellite retrievals. It is possible that relationships between cloud temperature, water content, and the distribution of particle shapes will be discovered and employed in retrievals of cloud properties. Existing aircraft data needs further analysis, and considerably more data for a variety of atmospheric conditions need to be collected. Field campaigns in tropical, mid-latitude, and polar regions should be used to supplement ground-based cloud lidar and radar measurements.

Surface bidirectional reflectivity plays an important role in clear sky shortwave radiative transfer. Until recently forward models did not include surface bidirectional reflectance functions (BRDF), and their availability is still very limited. This situation is expected to change in the near future, as empirical BRDFs for many surface types are being compiled from MODIS data. Additionally, surface BRDF measurements made during recent and future field experiments can be used to validate those based on MODIS data. Bidirectional emissivity is important for longwave radiative transfer, but few field measurements are available. Laboratory measurements are useful, but limited in scope.

There are several radiative transfer models available that use spherical harmonics, discrete ordinates, and successive orders of scattering in different combinations. There is general agreement in the results, but as computational efficiency is increased accuracy sometimes suffers. A good balance must be achieved. One standard of performance is the MODTRAN transmittance, radiance, and flux model that covers the visible to infrared part of the spectrum. DISORT, SHDOM, SHARM, 6S are also popular.

5.1.2 CrIS Radiative Transfer (Infrared)

The CrIS retrieval products are generated by minimizing the observed minus computed radiances. This places the fast forward radiative transfer model, which generates the computed radiances, on the same footing as the observed radiances. Consequently, validation of the forward model is as important as validation of the instrument radiances. The accuracy of the forward model is determined by the accuracies of its three main components, (1) the fundamental atmospheric spectroscopy that forms the core of the forward model, (2) the CrIS instrument model, or more specifically the CrIS instrument spectral line shape, and (3) the parameterization algorithm that converts monochromatic atmospheric transmittances into transmittances at the resolution of the CrIS radiances. In the past, component (3) has often received the most attention by retrieval system developers since the speed of the fast forward model was of primary importance, and because they did not have the expertise to improve the fundamental spectroscopy. During the last 10 years the fundamental atmospheric spectroscopy has improved tremendously based on a combination of new laboratory spectroscopy, theory, and intensive field campaigns/sites.

These improvements in spectroscopy are now approaching the estimated accuracy of the radiances measured by high-spectral resolution sounders and should remove the need to "tune" (or "bias correct") the computed radiances in order to force them to agree with radiances computed from other so-called truth such as radiosondes and/or NWP models. This is presently a common practice with HIRS on TOVS, and if continued in the EOS-AIRS and NPOESS era will severely limit the utility of the sounder products since they become tied to the accuracy of the radiosonde measurements and NWP models. We are now entering the era where the forward models may be significantly more accurate, in an absolute sense, than any other measurements of the atmospheric state for the time/space scales that a satellite sounder can sense. (For example, this is unquestionably true for upper atmospheric moisture, even for HIRS.) If we abandon the practice of "tuning" that forces the satellite retrievals to match the radiosonde measurements then the validation of the fast forward model becomes as important as the validation of the instrument radiances.

The high spectral resolution aircraft instruments developed by the IPO for NPOESS validation (NAST and Scanning HIS) are key tools for this work. Although significant progress has been made in recent years from data collected by aircraft and ground-based FTS instruments, important issues still remain. The data from AIRS onboard the NASA EOS Aqua spacecraft will also play a very significant role in validating forward models and ultimately understanding the information content in the radiances that is not present in NWP models. A significant focus on this effort is needed to make sure that the best possible models are available at NPP launch.

5.1.2.1 CrIS Validation Issues and Approaches

Validation of the CrIS fast forward model can be organized by the three main components outlined above. Forward model validation requires a common definition of the CrIS radiance product (SDR/Level 1B). This also impacts a variety of other validation efforts that require computation of CrIS radiances using various atmospheric truth data sets.

5.1.2.2 Fundamental Spectroscopy

The fundamental spectroscopy in the CrIS forward model is derived from monochromatic line-by-line radiative transfer algorithms that are nominally under continuous development by several groups. These include, for example, AER's LBLRTM and UMBC's kCARTA codes. At present, it is uncertain which line-by-line algorithm will be used in which segment of NPP. Moreover, the NWP centers have severe constraints on the form of their fast forward radiative transfer algorithms, and they will likely develop their own forward models based on some existing line-by-line algorithm. This suggests a dangerous situation where multiple users take the same radiances, but use different forward models resulting in different retrievals. These differences can arise not only due to differing spectroscopy but also due to different instrument line-shape models (and/or optional apodization approaches), and different parameterization approaches. A solution to this problem is discussed below.

There are a number of on-going laboratory studies, and future ground/aircraft campaigns that promise to improve the fundamental atmospheric spectroscopy in time for NPP. These "pre-flight" validation activities, funded by various sources including the IPO, need to be integrated into the line-by-line radiative transfer model(s) that are used to generate the CrIS forward model(s). At present there is no identifiable effort to ensure that new forward model validation results are inserted into the forward model used in the retrievals.

5.1.2.3 CrIS Instrument Line Shape Model

An accurate instrument model is key to production of an accurate forward model. This issue is complicated by the fact that retrieval groups may wish to use different additional apodizations in their forward models that make validation problematic. It is recommended to agree upon a single apodization, so that the forward model validation across agencies will be much easier. Ultimately, the instrument apodization model used for forward model development is validated by ensuring that this model also accurately reproduces the CrIS gas transmittances measured during pre-launch calibration.

5.1.2.4 CrIS Parameterization Model

The desire for high-speed forward models has always forced the use of semi-empirical parameterizations of the atmospheric transmittances. Validation of these parameterizations can primarily be performed internally by the algorithm developer. However, these parameterizations result from regressions using statistical sets of atmospheric profiles that may not be optimal for the retrieval system. Care should be taken to ensure that poor forward model performance under certain atmospheric conditions is not a result of a poor choice of regression profiles during fast forward model development.

Generally a wide variety of trace gas constituents have their profiles fixed within a fast forward model. Some of these gases can vary slowly over time. Validation of the parameterization should also include validation that these fixed values for various atmospheric gases are correct.

5.1.2.5 Pre-launch Activities

Pre-launch validation will draw upon activities within the AIRS and IASI science teams. These include use of surface, radiosonde, and aircraft data at NPP validation sites to simulate the CrIS spectral radiances. These activities should lead to improved radiative transfer formulation, and better performance stability of the products at global scale. Pre-launch activity will also include software preparation for validation data processing and analysis.

5.1.2.6 Post-launch activities

Post-launch validation activities will focus on the comparison of CrIS observations over NPP validation sites with radiances calculated using the forward model. Inputs for the forward model will come from ground instruments, radiosondes, as well as aircraft data. Performance accuracy will be budgeted for each site and in different climate regimes

The Government Team will strive to resolve any discrepancies observed between CrIS and the forward model calculations, and improvements should be proposed.

5.1.3 ATMS Radiative Transfer Model (Microwave)

Validation of a microwave radiative transfer model is an important component in the overall NPP cal/val activities and will begin during the pre-launch period. With the collocated data sets including atmospheric, surface, and satellite radiances, the radiance calculated from the model can be directly compared with the ATMS measurements and the error can be budgeted for each channel. In addition, the instrument performance such as antenna pointing angle and the polarization angle alignment can be assessed.

The most challenging issues and most of the uncertainty in microwave forward modeling are caused by surface emissivity; atmospheric scattering from clouds and precipitation; and spatial inhomogeneity. To simulate the surface emissivity, the Government Team will identify various emissivity models and assess their accuracies under various environmental conditions. Presently, the emissivity over oceans can be derived with fairly good accuracy (errors less than 1%) for the ATMS frequencies below 90 GHz using an empirical model. However, the simulation of the emissivitty at higher ATMS frequencies is yet to be determined. While the comprehensive microwave land emissivity models are being developed, the errors for the surface models need to be assessed at various ATMS channels.

The particle scattering from clouds and precipitation must be taken into account in ATMS radiance validation. To use the ATMS measurements for the direct radiance assimilation and climate applications, Government Team must validate the radiance accuracy under all weather conditions and assess the various schemes for computing atmospheric optical parameters, which are utilized in the radiative transfer models. In addition, the radiative transfer scheme including polarization and scattering should be evaluated by comparing the results with various bench-mark tests published in the literature.

The accuracy of any validation of the NPP science data products is dependent on precise characterization of both the atmospheric and surface states during the satellite observation. For ATMS validation cases, the uncertainties in knowledge of parameters such as temperature, water vapor and atmospheric hydrometeor profiles are crucial for the validation of the forward model, observed radiances, and science products.

5.1.3.1 Pre-launch Activities

Validation of the microwave forward models must be accomplished. The microwave emissivity significantly varies according to the surface types. Over oceans, the emissivity can be accurately estimated at most of ATMS frequencies using an empirical model (Wisler and Hollinger 1977) or a two-scale model (Yueh, 1997). Over land, the microwave emissivity model has been recently developed to predict the emissivity spectrum (Weng et al., 2001). Both models would be crucial for the ATMS radiance computation, especially for the channels “seeing” the surfaces. To validate the ATMS radiance at the cloudy and precipitation conditions, the microwave forward model can be generalized to include the scattering contributions. An improved description of the scattering properties of ice particles has been developed by Bennartz and Petty (2001). This approach leads to a consistent description of scattering over the entire frequency range of the ATMS. A fast polarimetric radiative transfer model (FASTPORT) has been recently developed by NESDIS scientists (Liu and Weng, 2001) and was proved to be very accurate, compared to the other sophisticated RT models. The Government Team will also evaluate other microwave forward models for the ATMS applications.

Validation of the microwave radiative transfer model is part of the overall NPP cal/val activities and will begin before launch. One element of this effort will utilize co-located clear-air satellite and aircraft infrared and microwave data sets to predict radiances for ATMS and other instruments that can be compared with observations to yield estimated potential errors for each channel of each participating instrument. This “round robin” calibration method is in lieu of a direct NIST involvement in the microwave region (see Section 4.5.2).. By relating these discovered errors to the limited degrees of freedom in the physical models and laboratory transmittance measurements, it is expected that all transmittance models can be evaluated and improved.

Because microwave and infrared spectrometers utilize single blackbody calibration loads across many frequencies, the calibration errors of channels with very different transmittances are generally highly correlated. Moreover, the information of adjacent pixels in both aircraft and satellite data sets are also often highly correlated, so they may be averaged, yielding the potential for discovering, through the round-robin technique, some transmittance-model-based radiance discrepancies of as little as 0.01-0.1K. Since it is unlikely that all microwave or IR frequencies would be offset in transmittance such that a single calibration offset (say 1K) could duplicate a typical multi-atmosphere ensemble of discovered error spectra, this hard-to-reduce systematic calibration error may not be limiting. This round-robin cross-calibration method should be tested for the first time during CY 2002 using NAST and satellites of opportunity.

5.1.3.2 Post-Launch Activities

To the extent that the transmittance models can not be improved or validated as suggested above, reliance must be placed on the absolute accuracies of the various calibration systems and protocols. Microwave calibration of NPP is discussed in Section 4.4

Two other challenging sources of uncertainty in field-based microwave transmittance tests are microwave surface emissivity and atmospheric scattering from clouds and precipitation. Clear-air tests at surface-blind frequencies should be primary for validating microwave clear-air transmittances, with emphasis on testing diverse atmospheric temperature and humidity profiles. For frequencies where surface emissivity limits ATMS transmittance validation accuracies, up-looking microwave observations offer an alternative. Unfortunately atmospheric water vapor can become dominant, so stable atmosphere and very precise collateral water-vapor profile determinations exactly coincident in time and space with transmittance observations are required. Similarly, nadir-viewing transmittance tests would require precise surface emissivity models validated under various environmental conditions.

In order to achieve more accurate retrievals of cloud parameter, the scattering properties of clouds and precipitation are needed to reconcile ATMS observations with atmospheric models. Aircraft observations at relevant ATMS frequencies are required over diverse clouds for this purpose because only aircraft instruments can resolve the complex structure of clouds (<~3 km) to the degree necessary to permit horizontally uniform models to be utilized.

5.2 Radiance Validation

Radiance validation consists of independent assessment of the spectral, spatial, and radiometric accuracy of the calibrated NPP radiances. For spectral validation, the efforts are focused on top-of-atmosphere calculations using known spectral features. For radiometric calibration, the primary validation for the visible and infrared channels of the NPP instruments is done with coincident observations from NPOESS aircraft instruments (MAS, NAST-I and S-HIS) and the EOS sensors, with top-of-atmosphere calculations using validation site atmospheric profiles and surface characterization. Ground instruments used at specific calibration sites are also considered in the validation work of the NPP radiance.

5.2.1 Visible, Infrared and Microwave Radiance Validation

The calibration and validation of NPP radiance measurements can be divided into two tasks - creation of validation data sets and comparison of NPP measurements to measurements from aircraft and other satellite instruments. The accuracy of any validation of the NPP science data products is dependent on precise characterization of both the atmospheric and surface states during the satellite observation. Validation cases, where the uncertainties in knowledge of parameters such as water vapor profiles have been determined, are crucial for the validation of the forward model, observed radiances, and science products.

Validation of NPP radiances falls into two categories: spectral and radiometric. The first deals with identification of inconsistencies due to VIIRS channel central frequencies and spectral response function full-width uncertainties, and confirmation of CrIS wavelength scale based on comparisons with spectra calculated from radiosondes. The second involves radiometric calibration from inter-comparisons with calculations using radiative transfer models of known accuracy. Absolute radiance validation can be performed by comparing the observed minus calculated radiance residuals between the NPP instrument data, and aircraft data (MAS, S-HIS, NAST-I, NAST-M) observations.

Another important activity that will contribute to the long-term validation of the NPP sensor radiance is the intercomparison with other coincident data (such as from the EOS Terra and Aqua platforms). Overlap between VIIRS and MODIS Terra observations is strongly encouraged in order to provide continuity for VIIRS EDRS. Currently, schedules show no overlap at all. Lack of overlap places demands on the cal/val effort to assure continuity that severely tax, and which may be beyond the capability required for seamless time series at the accuracy needed for climate research. We strongly urge NASA to consider extending the operation of MODIS Terra into the VIIRS time frame, assuming that it is still capable of providing useful data, for at least several months.

This will require participation in the definition of these intercomparisons in coordination with the various instrument teams. The Government Team proposes to demonstrate some of these calibration validation techniques using MODIS,AIRS and AMSU/HSB data as part of their participation in EOS Science Team activities. Intercomparison with EOS, GOES, POES, Meteosat, METOP, ENVISAT, EO-3 and GMS will be undertaken as well. The techniques developed in these intercomparisons will then establish an important part of the NPP sensors' calibration validation process.

The EOS calibration sites (e.g. White Sands, Railroad Playa) are highly relevant to VIIRS calibration and radiance validation activities. These sites already well characterized, have been used for many years as a calibration reference for the AVHRR bands and then MODIS. Ground instruments such as sunphotometer and radiometers, will be deployed along with aircraft flights to measure surface and atmospheric properties. These measurements will allow top of the atmosphere radiance calculations to be compared to

VIIRS observations. Discrepancies between observed and calculated radiance will determine the accuracy of the radiance and how well the on-board calibration sources are performing.

Comparisons of observed and calculated CrIS and ATMS radiances for forward model validation should be concentrated about those radiosonde launch sites that provide additional information about the state of the atmosphere and the surface. For example, the DOE ARM CART sites routinely operate microwave radiometers that provide atmospheric total precipitable water (TPW) measurements that are used to scale radiosonde water vapor profile to the same TPW amount. In addition, surface and near surface temperature and water vapor measurements are made that would impact the observed-calculated radiance bias.

5.2.2 Approaches for Routine Radiance Validation

NPP radiance products are validated on a routine basis using the following three approaches:

5.2.2.1 Radiance validation using NWP analysis

A very useful approach to validate CrIS and ATMS radiances is to compare them with radiances simulated from Numerical Weather Prediction (NWP) analysis fields. Analysis fields of temperature, moisture, and ozone are spatially and temporally interpolated to selected CrIS and ATMS FOVs. Radiances are computed using a fast radiative transfer model from the interpolated atmospheric state. The enormous sample provides the means to study and monitor scan dependent bias and standard deviation between measured and computed radiances. Time series of channel bias and standard deviation are updated daily. This capability will quickly detect apparent outliers and will also detect sensor drift.

5.2.2.2 Radiance validation using operational radiosondes.

Ensemble statistics of radiance residuals (bias and standard deviation) from radiance simulated from operational radiosondes provides a model independent validation. Approximately 300 matchups (collocated radiosonde and satellite FOVs) are available each day. Although operational radiosondes do not generally possess the accuracy neededfor spectroscopy validation, they are a very good source for long term monitoring. The collected data can also be used for radiance tuning. The use of similar radiosonde instrument quality is important. Selection of radiosonde type can be determined by comparing radiance residuals as a function of radiosonde instrument.

5.2.2.3 Radiance validation using eigenvector decomposition.

Eigenvectors of radiances can be used to validate radiance quality. This is achieved by reconstructing radiances using a truncated set of eigenvectors, then comparing it with observed radiance. If the difference is very large then the radiance quality is questionable.

5.2.3 Approaches Planned for Radiance Validation

These NPP radiance products (SDR produced at IDPS and Level 1B produced at SDS) are to be validated as a combination of three strategies:

1- **Aircraft under-flight measurements**
2- **Ground measurements at NPP calibration sites**
3- **Inter-comparison to other space-based sensors**

5.2.3.1 VIIRS radiance validation

Approach 1: Aircraft Visible, Near Infrared and Thermal Observations
Product: VIIRS radiance validation
High altitude airborne measurements from MAS and/or MASTER instruments will be conducted at EOS calibration sites and/or over ocean sites, and the estimates will be compared to VIIRS measurements, assuming most of the atmosphere is below the aircraft.

Viewing geometry and temporal acquisition will be addressed to avoid any variation linked to the viewing observation, surface heterogeneity or atmospheric fluctuations. Means of measured radiance from airborne sensors will be compared. The observed radiance difference is then attributed to calibration differences or sensor characterization changes.

Approach 2: NPP Validation Sites Radiance Measurements
Product: VIIRS radiance validation
The approach is to compare VIIRS cloud-free radiance spectra to calculations of the upwelling clear sky radiance for NPP overpasses of the NPP calibration validation sites. These sites will be chosen for their surface uniformity and stability. The calculations will be performed using well-calibrated ground and tower radiometers or/and spectrometers, and temperature and water vapor best estimate products from the NPP validation site. The radiative transfer codes will be used to perform these top-of-the atmosphere radiance calculations. The differences between the observed and calculated radiances will be analyzed with respect to the calculation uncertainties (spectroscopic accuracy, radiative transfer and atmospheric state uncertainty, and surface emissivity and temperature characterization) to assess the accuracy of the observed radiances.

Approach 3: Space-Based Sensors Cross-Validation
Product: VIIRS radiance validation
Sensor from other programs such as EOS, METOP and ENVISAT programs will be used in this sensor cross-validation. Resampling methods will be provided to minimize errors from geolocation processing and spectral differences. Comparisons of the sensor radiances are then made for selected scene types of varying homogeneity and signal level (e.g. clear ocean, desert, vegetation, etc…).

Viewing geometry and temporal acquisition will be addressed to avoid any variation linked to the viewing observation, surface heterogeneity or atmospheric fluctuations. Means of measured radiance from space-based sensors will be compared. The observed radiance difference minus the forward-calculated clear sky radiance difference is then attributed to calibration differences or sensor characterization changes.

5.2.3.2 CrIS radiance validation

Approach 1: Aircraft Infrared Radiance Observations
Product: CrIS radiance validation
Uniform targets with a range of radiance levels (e.g. uniform ocean for a range of latitudes, deserts, and uniform cloud decks) will be selected. Aircraft field campaigns in which NAST under-flights will be made with aircraft flight tracks arranged parallel to the sub-satellite track, and where the aircraft view-angle will be adjusted to match the appropriate CrIS cross-track angle. The approach is to compare both CrIS and aircraft spectral radiances at a common spectral resolution. This is possible since the NAST-I and S-HIS are both Fourier Transform Spectrometers as is the CrIS sensor. The higher resolution aircraft pixels are summed with appropriate weights to represent the larger CrIS Spatial Response Function. Unsampled regions are represented by using imager data to assign spectra from similar sampled regions.

Approach 2: NPP Validation sites TOA Radiance Calculations
Product: CrIS radiance validation
The basic approach is to compare CrIS cloud-free and cloud-cleared radiance spectra to calculations of the upwelling clear sky radiance for NPP overpasses of the ARM sites, P-AERI sites and ocean sites (ship cruises). The calculations will be performed using inputs for temperature and water vapor best estimate products. The CrIS fast model and line-by-line radiative transfer codes will be used to perform these clear sky calculations. The differences between the observed and calculated radiances are then analyzed with respect to the calculation uncertainties (spectroscopic accuracy, fast model parameterization, atmospheric state uncertainty, and surface emissivity and temperature characterization) to assess the accuracy of the observed radiances. The Atmospheric and Environmental Research Inc. (AER) Optimal Spectral Sampling (OSS) radiative transfer model will be compared to other fast transmittance models (including a PFAAST-based model for CrIS). These comparisons will be done separately for cloud free and cloud cleared conditions to assess the accuracy of the clear sky CrIS radiances and the accuracy of the cloud-clearing algorithm and resulting radiances under cloudy and partly cloudy conditions.

Approach 3: Space-Based Sensors Cross-Validation
Product: CrIS radiance validation
The general technique is to reduce the data from different sensors to the same spectral and spatial resolution using appropriate averaging methods. Comparisons of the sensor radiances are then made for selected scene types of varying homogeneity and signal level (e.g. clear ocean, desert, etc…). Collocation in space and time is required. Spatial and temporal scaling should be robust enough to avoid any variation that can be linked to the

surface or atmospheric fluctuations. Furthermore, data will be selected close to nadir for each instrument in order to minimize viewing angle differences. Means of measured radiance from space-based sensors will be compared. Clear sky forward calculations (using a global model for estimation of the atmospheric state) are performed to account for differences in the spectral response functions (when comparing to broad band radiometers). The observed radiance difference minus the forward-calculated clear sky radiance difference is then attributed to calibration differences.

5.2.3.3 ATMS radiance validation

Approach 1: Aircraft Microwave Radiance Observations
Uniform targets with a range of radiance levels (e.g. uniform ocean surface for a range of latitudes, deserts, and uniform cloud decks) will be selected. Aircraft field campaign in which NAST under-flights will be made with aircraft flight tracks arranged parallel to the sub-satellite track, and where the aircraft view-angle will be adjusted to match the appropriate ATMS cross-track angle. The approach is to compare both ATMS and NAST-M aircraft spectral radiances at a common spectral resolution from NAST-M. The higher resolution aircraft pixels are summed with appropriate weights to represent the larger ATMS Spatial Response Function (SRF). Unsampled regions are represented by using imager data to assign spectra from similar sampled regions.

Approach 2: NPP Validation Sites TOA Radiance Calculations
The basic approach is to compare ATMS radiance spectra to calculations of the upwelling clear sky radiance for NPP overpasses of the ARM sites. The calculations will be performed using input from the ARM site temperature and water vapor best estimate products from the Southern Great Plains (central facility), North Slope of Alaska (Barrow site), and the Tropical Western Pacific (Nauru) sites. The ATMS fast model will be used to perform these calculations under clear and cloudy conditions. The differences between the observed and calculated radiances are then analyzed with respect to the calculation uncertainties (spectroscopic accuracy, fast model parameterization, atmospheric state uncertainty, and surface emissivity and temperature characterization) to assess the accuracy of the observed radiances.

Approach 3: Space-Based Sensors Cross-Validation
Sensors from other programs such as EOS, METOP and EO-3 programs will be used in this sensor cross-validation. Resampling methods will be provided to minimize errors from geolocation processing and spectral differences. Comparisons of the sensor radiances are then made for selected scene types of varying homogeneity and signal level (e.g. clear ocean, desert, vegetation). Viewing geometry and temporal acquisition will be addressed to avoid any variation linked to the viewing observation, surface heterogeneity or atmospheric fluctuations. Measured means of radiance from space-based sensors will be compared. The observed mean of the radiance difference minus the forward-calculated clear sky radiance difference is then attributed to calibration differences or sensor characterization changes.

5.3 Spatial co-registration validation

The spatial co-registration will be addressed in the Level 1A (RDR) algorithms for VIIRS, CrIS and ATMS by NPP instrument vendors.

Level 1A processing involves unpacking and verifying RDRs, organizing these data into scan oriented data structures, generating the Earth location data, adding associated ancillary information (metadata) required to describe the data set, and producing a data product in a standard format.
In this context, the Earth location data fields are treated as additional attributes of the spatial elements that contain the science data, thus describing explicitly each spatial element's ground location.

A set of parametric equations and a table of sub-pixel corrections for each detector or band will be included in the data product to capture the effects of band-to-band and detector to detector offsets.

5.3.1 Instrument and spacecraft alignment data verification

The geometric characterization and calibration of instrument, spacecraft, and ancillary data are integral to the verification process. Geometric calibration activities to be performed by the instrument and spacecraft contractors will be carried out in accordance with their contract schedules. Specifically, the preflight instruments' geometric calibration will be performed by the corresponding vendors for each instrument following their calibration plan.

The Government Team is responsible for the oversight of these measurements. Of particular interest to the Earth location model, are the absolute orientation, mirror positioning, MTF, band-to-band registration, and antenna tests. Preflight measurements of the instrument-to-spacecraft alignment will presumably be carried out during the instrument/spacecraft integration phase.

5.3.2 Band-to-Band Registration (BBR) verification

Approach 1: Earth scenes with high contract features
High contrast scenes, such as coastline, will be used for the band-to-band co-registration. Because of continuous global coverage by the sensors, this approach will have plenty of data sets. Scenes with gradients in surface features will also be used for this purpose.

Approach 2: Lunar view
The moon serves as a fairly stable radiometric source and it will be used for long-term sensor response stability monitoring, especially for the reflective solar bands. Lunar view responses from different spectral bands will be used for BBR characterization. This approach has been successfully used in the MODIS on-orbit BBR monitoring.

5.3.3 Instrument-to-Instrument Registration

In addition to pre-launch spatial characterization that includes the determination of band-to-band registration, it is essential to validate and monitor on-orbit variation of BBR and its long-term stability. For sensors with multi-focal plane assemblies, this also includes the co-registration among different focal planes. For comparison of science products derived from different sensors, sensor-to-sensor co-registration is also needed. Most likely this can only be done from on-orbit observations.

If possible, both along scan and along track directions co-registrations should be considered. In the following, a number of potential approaches are listed based on the sensor type.

CrIS and ATMS spatial co-registration

The Nyquist-sampled character of ATMS data permits "sharpening" of ATMS images beyond their nominal 15- or 50-km nadir resolution. By comparing the average response of CrIS and ATMS to unresolved isolated islands, lakes, and precipitation cells, the average relative offsets of these two sensors should be determined empirically to within ~2 km. If ATMS is not Nyquist sampled, this task would be more difficult.

5.3.4 Sensor Navigation Validation

The goal of navigation validation is to ensure that the radiances and atmospheric profiles are navigated to Earth located footprints to the required accuracy. Candidate approaches include the comparison of sensor images to calculated images for well defined, high contrast coastlines and similar surface features, and the comparison of coarse and high resolution sensors such as CrIS and VIIRS.

6 Level 2 and Higher Product Post-launch Validation

Product validation is the process of assessing by independent means the accuracy of the geophysical products derived from each instrument. Validation establishes the accuracy or confidence levels associated with each retrieval algorithm geophysical product over the range of scene conditions associated with the retrieval. Figure 6.1 illustrates some of the elements associated with the validation process.

Validation of satellite data, both on a global and a regional scale, are usually conducted in several ways using multiple (independent) measurement approaches.

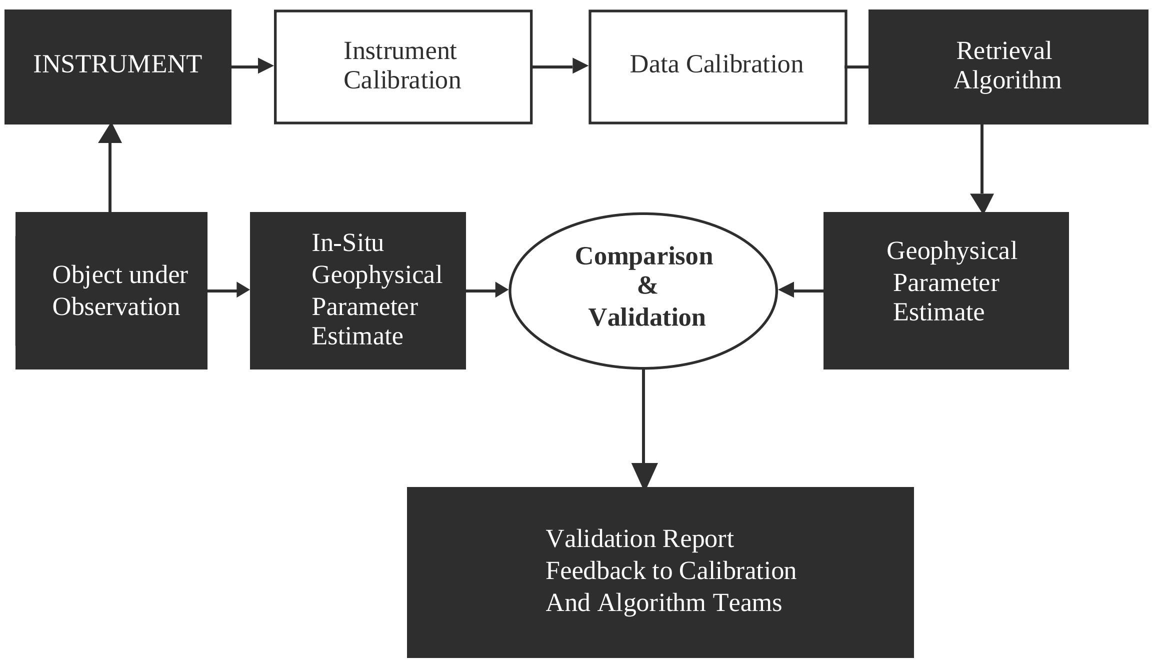

Figure 6-1: High Level Schematic of the EDR/CDRs Validation Process

Experience and strategies learned during the pre-launch period will be applied to the post-launch EDR validation activities. The EOS validation period will be complete before the launch of NPP platform. This will be an invaluable resource for the final validation plans for NPP instruments.

Ground and aircraft-based as well as satellite over-flights of well-instrumented land stations, such as those presented in this section, will also provide a large data set for the EDRs validation process. Coordinating efforts with NPOESS and other platforms' based sensors will be a high priority in order to lower costs and provide cross-suite validation capabilities.

In order to validate NPP data products, it is necessary to validate land, ocean and atmospheric parameters under a wide variety of atmospheric conditions, solar illumination and viewing angles, and over a wide variety of ecosystems worldwide.

In the following sections, we will provide guidelines for VIIRS and CrIS/ATMS product validation. A list of validation approaches for each of the EDR/CDRs is provided in the Appendix H.

6.1 Validation of Groups of NPP Products

The NPP Level 2 products (EDR/CDR) are categorized into six groups: (1) Atmospheric Sounding, (2) Aerosol, (3) Clouds, (4) Land, (5) Ocean, and (6) Snow and Ice. These products are to be validated as a combination of three strategies, shown in Table 6-1.

Table 6-1: NPP Validation Strategies

1. **Surface Validation Sites**
   - 1a. Atmospheric State
   - 1b. Land Surface Characteristics
   - 1c. Oceanographic Research Vessels/Buoy Systems
2. **Airborne Validation Platforms**
   - 2a. Piloted Aircraft with Radiometric Sensors
   - 2b. Unmanned Airborne Vehicles
   - 2c. Commercial Aircraft
3. **Satellites Cross Validation**
   - 3a. Advanced Satellites
   - 3b. Operational Satellites

Field programs, conducted to generate research data sets, will be leveraged to bring together a wide variety of surface-based, airborne, and satellite data products for the purpose of validating NPP SDR/Level 1B and EDR/CDR products. Table 6-2 shows validation strategies that might be used to validate the NPP EDRs and CDRs, and also provide the level of priority to be allocated to validation strategies for each NPP product.

Table 6-2: Validation Strategies for NPP EDR/CDRs

		Strategy **							
		1a	**1b**	**1c**	**2a**	**2b**	**2c**	**3a**	**3b**
EDRs	**Imagery** *							X	Y
	Moisture Profile *	X			X	Y	Z	Y	Z
	Temperature Profile *	X			Y	Y	X	Y	Z
	Pressure Profile	X							
	Precipitable Water	X	X	X	X	Y	Y	X	Z
	Suspended Matter		X					Y	
	Aerosol Optical Thickness	X		X	X	X		X	
	Aerosol Particle Size	Y		Y	X	X		Z	
	Cloud Base Height	X		X	X	X	Y	X	
	Cloud Cover/Layer	Y		Y	X	X		X	Z
	Cloud Effective Particle Size	Z		Z	X	X		Y	
	Cloud Optical Path	Y		Y	X				
	Cloud Top Height, Pressure/Temperature	Y		Y	X	X	Z	Y	Z
	Active Fires							X	Y
	Albedo (Surface)		X	Y	X				X
	Land Surface Temperature	Y	X		X	X		Y	Z
	Net Heat Flux	X	X	X	Y				
	Soil Moisture	X	X		Y	Y		Z	
	Surface Type	X	X		Y	Y		Z	
	Vegetation Index		Y		Y	X		Y	Z
	Ocean Color and Chlorophyll			X	Y	X		Y	Z
	Sea Surface Temperature *			X	Y	Y		Z	
	Sea Ice Characterization			X		Y		X	Z
	Ice surface Temperature			X	Y	X		Y	Z
	Snow Cover and Depth	X	X						
CDRs	Clear Column Radiance	X			X	Y		Y	Z
	Ozone	X			X			Y	Z
	Precipitation Rate	X						Y	
	Trace Gasses	X			X	Y		Y	
	Cloud Ice Water	X			X	Y			
	Cloud Liquid Water	X			X	Y			
	Atmospherically Corrected Reflectance	Y			X			Y	
	Active Fire	X						Y	
	LAI/FPAR	X			Y			Y	
	Sea Surface Temperature			X	Y	Y		Z	
	Ocean Color (Water Leaving Radiance)			X	Y	Y		Z	

X: Highest Priority Y: Medium Priority Z:Lowest Priority
* NPP Primary EDRs ** See Table 6.1 for validation strategies

6.1.1 Surface Validation Sites

The surface validation sites make use of resources already established around the globe for weather observations, climate monitoring, and atmospheric and land surface process research. These sites accommodate a wide variety of remote sensing and in-situ measurement devices. Table 6-3 describes the primary surface validation sites, and available data products to be acquired from this extensive network of stations.

Table 6-3: NPP Ground Validation Sites

Network	Location	Primary purpose
AERONET	Multiple locations in North America, South America, Europe, Africa, Asia, and Oceania.	Aerosol optical thickness, columnar aerosol size distribution, and precipitable water.
ARM	Southern Great Plains, North Slope of Alaska, Western Tropical Pacific	Cloud base height, temperature and moisture profiles, sky radiance, integrated liquid water path
EOS	North America, Brazil UK, RSA, Zambia, Russia, Mongolia, Australia	Aerosols, radiance, temperature, surface biophysical parameters
SIMBIOS	Global (U.S. and international ocean color validation cruises)	Water-leaving radiances, atmospheric optical data, marine pigment concentrations.
RAOBS	Global, primarily northern hemisphere over land	Temperature and moisture profiles, clear sky radiance (with forward model)
FARS	University of Utah	Cloud mask, cloud boundaries and microphysical structure, aerosol vertical profile
CIGSN	Australia	Clear irradiance, clear sky radiance for calibration comparison of MODIS radiances, radiosondes, sun photometer.
P-AERI	South Pole	Clear sky radiance (IR) and surface measurements for MODIS validation of cold scenes.
Balloon	North America	Balloon-born Ice crystal replicators for size distribution and habit of ice crystal in upper atmosphere.
SuomiNet	Primarily North America	GPS derived integrated column water vapor
Ozonesonde Network	Global, Primarily northern hemisphere mid-latitudes	Ozone profiles

The calibration and validation of ocean products will make use of research vessels with spectral radiometers viewing the sea and the atmosphere (e.g., M-AERI), active LIDARS and RADARS, and in-situ measurement devices.

6.1.2 Airborne Validation Platforms

Piloted research aircraft (e.g., ER-2 and Proteus, P-3, C-130, DC-8, WB-57, Twin Otter) carrying a variety of active and passive radiometric sensors will be used in field programs to provide high spatial resolution validation data. Aircraft such as the ER-2 and Proteus will be capable of flying over wide range of altitudes, including vertical profiling which enables precise validation of radiative transfer models and retrieved atmospheric and surface parameters. Unmanned airborne vehicles (e.g., the Global Hawk) will enable a global sampling of surface (land and ocean) and atmospheric products over a wide range of geographical and atmospheric conditions in a single flight. Commercial aircraft equipped with meteorological sensors (e.g., ACARS) will provide time coincident atmospheric sounding validation data obtained during ascents and descents near airports around the globe.

6.1.3 Satellite Sensor-to-Sensor Cross-Validation

Advanced polar and geostationary satellites to be in orbit during the NPP mission (e.g., EOS, METOP, ESSPs, EO-3, ENVISAT, etc.) will carry sensors with comparable, or better, spectral and spatial resolution to those sensors to be carried on the NPP platform. The products of these sensors will provide an important cross-validation of the NPP geophysical products. This is particularly important with regards to METOP and EO-3 since products from these satellites, and their operational successors, are intended for use in combination with NPOESS products to provide a global high spatial and temporal resolution data set for climate research and operational weather forecast applications. Well-characterized products of operational satellites (e.g., NOAA, GOES, and Meteosat) will also provide valuable satellite cross validation data.

6.2 Activities Supporting NPP Products Validation

The NPP products validation effort benefits greatly from the infrastructure of several existing programs, including the EOS, POES and DMSP programs

For the CrIS/ATMS, the validation will be largely based on the AIRS and GIFTS experience. Cross-sensors validation with AIRS, GIFTS, and IASI are planned, as well as aircraft campaigns with the NAST and S-HIS. The NWP analysis and radiosonde data will play a significant role in the routine products evaluation. Detailed approaches for CrIS/ATMS EDRs/CDRs can be found in Appendix H.

For the VIIRS, the validation will benefit greatly from MODIS and AVHRR experience. Cross-sensor validation are planned, as well as aircraft measurement inter-comparisons using MAS, MQUALS and AVIRIS data. Atmospheric data from AERONET network, buoys and ship-based ocean measurements, and land biophysical parameter measurements from towers at EOS core sites will provide routine evaluation of VIIRS products. Detailed approaches for VIIRS EDRs/CDRs can be found in Appendix H.

In the production of most Level 2 and higher products, ATMS radiances will generally be aggregated with CrIS and other data, and lose their unique identity. Similarly, in any aircraft validation campaign, airborne and ground-based microwave sensors will typically also be aggregated with other sensors to produce the validating product, as is being demonstrated by NAST-I and NAST-M. A key role of these validating airborne and ground-based microwave sensors will be to penetrate cloud and haze to a degree not achievable at shorter wavelengths. This role will be critical for validation of products such as precipitation rate; temperature, humidity, and precipitation profiles; cloud particle size, liquid water content, and cell top altitude; snow cover, depth, and type; and sea-ice cover and type.

6.3 Routine Validation Approaches

6.3.1 Product Validation Using NWP Analysis

Differences between EDR and analysis fields provide very useful information about the quality of the retrieval. Large differences may indicate problems in the retrieval. Coherent patterns may also indicate problems in the forecast. Further inspection using campaign data or operational radiosondes will determine if the problem is in the EDR or in the analysis. Further confirmation can be achieved by comparing EDR fields from other sensors (e.g. AIRS, IASI, ATOVS). Differences as a function of view angle will allow detection of scan dependent errors.

6.3.2 Product Validation Using Operational Radiosondes

Statistics of EDR error using operational radiosondes network provide a model of independent validation. Temporal and spatial filtering is used to ensure that the radiosonde location and time is similar to the CrIS/ATMS EDR. Monitoring of EDR accuracy provides long-term validation, using approximately 300 radiosondes and satellite data matchups collected each day.

6.3.3 Regeneration of Products Using Ancillary Data

One approach for detecting possible inadequacies in EDRs is to regenerate the EDR with different initial conditions. For example, a CART site may show that the Level 1 data is of high quality, but the EDR is not. The problem may be due to a poor estimate in the initial surface emissivity that can be proven by regenerating the EDR using the emissivity measured at the CART site. The capability to regenerate retrievals is important.

6.3.4 Product Validation Using Sun-photometer Networks (AERONET)

AERONET is an optical ground based aerosol monitoring network and data archive supported by EOS. AERONET provides hourly transmission of CIMEL sun-photometer data to the GOES (or METEOSAT) geosynchronous satellites, which in turn relay the data to GSFC for daily processing and archiving. By teaming with NPP, science teams should have access to validation data from a global network of CIMELs in near real-time. This existing network will help in pre-launch and post-launch validation of the aerosol optical thickness, aerosol particle size, and spectral reflectance products.

In addition to routine data collection, several new methods for data collection were prototyped, most notably a CIMEL sun-photometer modified to sample surface-reflected radiances from a tower top position.

6.3.5 Product Validation Using Ship Cruises and Buoys

Validation data will be collected from ships, fixed platforms, and moored and drifting buoys. While sites such as MOBY will be used primarily for vicarious calibration of the ocean reflectance bands, data from a wide variety of "bio-optical" provinces is needed for product validation. These provinces include coastal regions, mid-ocean gyres, high latitudes, equatorial, and large scale frontal regions where changes in phytoplankton composition and dissolved and particulate absorption and scattering properties may affect algorithm performance. Similarly, accurate skin temperature measurments from shipboard radiometer and bulk temperature measurements from drifting and moored buoys will be used for SST validation. The suite of ocean color observations and the protocols for these measurements required for validation is continuously being refined under the SIMBIOS program. The data collected during these operations will be quality controlled and archived. The current archive of ocean color data is jointly supported by the SeaWiFS and SIMBIOS projects.

6.3.6 Product Validation Using Tower Data (EOS Validation Core Sites)

A global array of test sites will be available for comprehensive terrestrial surface measurements from EOS sites, and a global organization of many regional networks of CO2 / H20 flux towers, including AMERIFLUX for North America, EUROFLUX for Europe, OZFLUX for Australia and New Zealand. additional stations in South America developed by LBA, and stations being organized in Japan and China can also contribute with tower data. The Oak Ridge DAAC will be the point of FLUXNET data archive and distribution. Land surface characteristics such as albedo, bi-directional reflectance, LAI, FPAR, and other atmospheric measurements from towers top positions will be used for product validation.

6.4 Planned Validation Approaches for NPP EDR Operational Products

This section provides a list of validation approaches considered in the NPP EDR/CDR product validation. An attempt to develop a priority sequence is provided in the Appendix H for each product from high priority to optional/low priority. For a specific EDR/CDR, validation approaches listed as number 1 is high priority, and the last approach listed is optional or low priority. Additional information on the technique and estimated uncertainties for each validation approach are given in the Appendix H.

Some EDRs/CDRs have more than three approaches considered for product validation. Only approaches with required funding will be implemented.

6.4.1 Validation Approaches for Atmospheric Sounding Products

6.4.1.1 Atmospheric Sounding Validation (Moisture, Temperature and Pressure) (Primary EDRs)

Approach 1: Atmospheric profiles using ARM Sites' Observations
The basic technique is to use the routine ARM site observations (at the Southern Great Plains site in central Oklahoma, at the North Slope of Alaska site in Barrow, Alaska, and the Tropical Western Pacific site in Nauru) along with dedicated NPOESS overpass radiosondes to measure the temperature and water vapor profiles for validation of the CrIS retrievals. Temporally continuous profiling at the ARM sites will be used to assess small scale spatial variability. GOES, surface networks, and the relative variability of the single-FOV CrIS retrievals will be used to address larger scale spatial gradients. Best estimate profiles and quantitative error estimates will be provided and compared with the coincident CrIS retrieved profiles which have been interpolated in space (using single-FOV CrIS retrievals) to the validation profile locations.

Approach 2: International radiosonde sites
High quality radiosondes are at the core of in-situ measurements that scientists can use for NPP validation of measurements and derived products. Long term and global coverage of these in-situ measurements are keys to the statistically meaningful validation for atmospheric vertical profiles (water vapor, temperature and pressure). Some of the sites also have the potential to build an NPP direct broadcast (DB) receiving station and will be able to obtain real time NPP data. The basic approach is to make measurements of temperature and water vapor profiles coincident with CrIS retrievals via overpass-coordinated radiosonde launches. Sonde water vapor calibration errors will be addressed by scaling the sonde integrated column water vapor to values measured by a GPS or MWR, or alternatively by scaling to point measurements made with a high quality meteorological station coincident with the sonde measurements just prior to launch. VIIRS data will be used to assess cloud cover and spatial and temporal variability.

Approach 3: Retrievals from NAST-I and S-HIS aircraft observations at ARM
For high altitude NAST-I and/or S-HIS underflights of the CrIS overpasses, retrievals of atmospheric water vapor and temperature profiles derived from the NAST-I and/or S-HIS observations will be compared to the CrIS products. Cross-track scanning will allow the aircraft observations to be averaged to match the CrIS footprint. The flight paths and sensor scan angles can be tailored to match the CrIS viewing angles. These flights should be performed at maximum aircraft altitude. A complimentary technique is to perform slow ascents with the aircraft sensors to derive profiles from NAST-I and/or S-HIS data using opaque spectral channels which represent the local temperature and gas concentrations. Due to the slow ascents, these comparisons would be performed on a limited scope for stable, homogeneous meteorological conditions in order to provide meaningful comparisons to the CrIS product.

Approach 4: Comparison to Other Satellite Retrievals
Water vapor and temperature vertical profiles from EOS (AIRS), EO-3 (GIFTS), METOP (IASI) and other programs will be compared to those derived from CrIS/ATMS through the annual cycle on a global basis. Collocation in space and time is required. Spatial and temporal scaling should be robust enough to avoid any variation that can be linked to the surface or atmospheric fluctuations. Furthermore, data will be selected close to nadir for each instrument in order to minimize viewing angle differences. Means of measured water vapor and temperature from space-based sensors will be compared for different climate regimes and surface types.

Approach 5: WVSS (ACARS water vapor observations)
Water vapor (and temperature) measurements provided from Water Vapor Sensor System (WVSS) units mounted on United Parcel Service (UPS) aircraft offer another source of water vapor information complementing radiosondes, an Atmospheric Emitted Radiance Interferometer (AERI), global positioning system, Vaisala ceilometer, and surface meteorological stations. Preliminary results from prior intercomparisons indicate WVSS water vapor measurements are of reasonable quality above the boundary layer, however they exhibit a moist bias that occurs during ascent and descent through the boundary layer. This problem has been corrected with the WVSS-II, which shows improved performance in accuracy due to a single mode diode laser, probe placement on aircraft, and longer maintenance intervals. Ascending and descending aircraft WVSS-II data will be intercompared to CrIS moisture profiles.

6.4.1.2 Total Precipitable Water (TPW) (EDR)

Approach 1: Comparison to AERONET data
The AERONET network of sun photometers will continue to provide the most viable total precipitable water validation source. AERONET consists of a global network of approximately 100 sunphotometers measuring in several channels in the visible and near-infrared spectrum. The AERONET data can also be used to derive the spectral total column aerosol optical thickness and size distribution.

Approach 2: Comparison to EOS products
VIIRS and/or CrIS/ATMS TPW products will be compared with those from MODIS and AIRS/HSB, and probably to other future space-based sensors. These satellite retrievals will be compared statistically over large areas (land and ocean) (histograms over large areas, angular and geographical trends). This exercise will allow the detection of differences in calibration between these instruments and the assessment of the correctness of the VIIRS and/or CrIS/ATMS calibration requirements in each channel intended for TPW retrieval.

6.4.1.3 Suspended Matter (EDR)

To be included.

6.4.2 Validation Approaches for Aerosol Products

6.4.2.1 Aerosol Optical Thickness and Aerosol Particle Size (EDRs)

Approach 1: AERONET Comparisons
VIIRS retrievals will be matched with the NASA AERONET locations of surface based multi-spectral sun-photometer observations, as has been done for AVHRR, MODIS and VIRS. Linear regression analysis will be performed from daily match-up data sets to predict satellite retrieved AODs and APS based on AERONET sun-photometer observed values. Retrieval algorithm performance (systematic and random errors) can be identified from the statistical parameters of the linear regression, including intercept, slope, standard error, and correlation coefficient. For example, a non-zero intercept indicates that the retrieval algorithm is biased, most likely the result of instrument calibration errors or improper assumptions about the ocean's surface reflectance. Departure of the slope from unity suggests that there may be some inconsistency between the aerosol micro-physical model used in the retrieval algorithm (such as refractive index and/or size distribution) and the real world aerosol. Additionally, AERONET validation provides information that can be used to explain anomalies appearing in the self-consistency checks.

Approach 2: POES and EOS comparisons
VIIRS aerosol products will be compared with those from MODIS, AVHRR and VIRS. These three satellite instrument retrievals will be compared statistically over large oceanic areas (histograms over large areas in the southern-hemisphere, angular and geographical trends). Also, AVHRR and VIRS radiance look-up-tables (radiometrically adjusted, as needed, to better match the MODIS spectral response functions) will be applied to the most closely corresponding individual MODIS channels, and AOD and APS will be derived and evaluated. This exercise will allow the detection of differences in calibration between these three instruments and the assessment of the correctness of the VIIRS calibration requirements in each channel intended for aerosol retrieval.

6.4.3 Validation Approaches for Cloud Products

6.4.3.1 Cloud Base Height
To be included

6.4.3.2 Cloud Cover/Layer Validation (EDR)

Approach 1: MAS and MODIS comparisons
The VIIRS CC/L algorithm will be validated against MAS data and MODIS data along the imagery track centers where Lidar Cloud Profiling data is available. By inspection, a set of ground truth layered cloud amounts will be determined. These will then be compared to CC/L layered assessments and a qualitative indication of CC/L performance can be attained. At least one case of MODIS data will be used to validate CC/L algorithm performance. The CC/L product will be validated with independent cloud measurements either from space or other indirect means.

6.4.3.3 Cloud Effective Particle Size Validation (EDR)

Approach 1: Aircraft replicator profiles from Cloud Particle Imager (CPI) and MODIS. VIIRS Cloud Particle Size product will be validated at ARM and EOS sites. VIIRS assessments will be compared to the CPI measurements, and to MODIS retrievals.

6.4.3.4 Cloud Optical Thickness/Transmittance

To be included

6.4.3.5 Cloud Top Height/Pressure/Temperature (EDR)

Approach 1: Micropulse Lidar (MPL) and Cloud Radar (MMCR)
This approach uses the ARM site ARSCL product to validate the cloud top heights. ARSCL combines the MPL and MMCR measurements into a single product of cloud layers (base, top, thickness) versus time at each of the primary ARM sites (Southern Great Plains (SGP), Tropical Western Pacific (TWP), and North Slope of Alaska (NSA)). The technique then is to perform temporal averaging of the ARSCL product that produces an equivalent spatial averaging to match the extent of the footprint at that ARM site overpass time and compare the averaged product to the VIIRS product. Winds data from the Wind Profiler network (for SGP), model data, and/or sondes can be used to determine the averaging times.

6.4.4 Validation Approaches for Land Products

6.4.4.1 Active Fires (EDR)

Approach 1: POES and EOS comparisons
The fire area and temperature products will be compared to retrievals from other sensors, such as AVHRR and MODIS.
Statistical relationships will be established between AVHRR, MODIS and VIIRS derived fire products over specific areas and time periods. Results of this study will be useful for the construction of a continuous AVHRR-MODIS-VIIRS data record of fire occurrences for long-term studies.

6.4.4.2 Surface Albedo Validation (EDR)

Approach 1: Pyranometers and albedometers data (ground and aircraft based)
A tower-based albedometer will be used to generate highly accurate data at very high temporal resolution at minimal cost. However albedometer's spatial field of view is limited by its relatively short distance above the vegetation, and its fixed position. These point data can be scaled to approximate larger area albedo fields. Scaling techniques are being developed at this time. To sample much larger areas, some scientists have mounted albedometers on aircraft. This approach appears promising (at least one instrument vendor recently developed a pyranometer with appropriate thermal stability for aircraft use),

however it is expensive, and data may need to be corrected for atmospheric effects (depending on aircraft altitude), geolocation, and aircraft attitude. Because albedometers essentially measure a quantity equivalent to the albedo EDR product (assuming appropriate spatial scaling), comparison of in-situ data to EDR values is straightforward. Advancement of albedo measurement and scaling approaches will presumably result from the EOS validation program.

Approach 2: POES and EOS comparisons
Albedo products from other sensors, such as MODIS, AVHRR and GOES will be compared to VIIRS and CrIS LST retrievals. The comparisons will be conducted under a variety of atmospheric and surface conditions.

6.4.4.3 Land Surface Temperature (LST) (EDR)

Approach 1: S-AERI measurements
The DOE SGP ARM site and EOS sites will be used for VIIRS and CrIS LST validation. Surface temperature and emissivity will be collected from the S-AERI system co-incident with NPOESS overpasses on a limited campaign basis. Coincident imager data from the NPOESS platform will also be acquired.

Approach 2: S-AERI measurements
High altitude flights of ER2 and/or the Proteus beneath the NPP will be conducted with the MAS and NAST-I instruments. Micro-windows will allow for determination of the LST under minimal atmospheric attenuation conditions. Comparison of MAS and NAST-I LST retrievals to VIIRS and CrIS LST products will be conducted under a variety of atmospheric and surface conditions.

Approach 3: POES and EOS comparisons
LST products from other sensors, such as MODIS AVHRR, GOES, AIRS and GIFTS will be compared to VIIRS and CrIS LST retrievals. The comparisons will be conducted under a variety of atmospheric and surface conditions.

6.4.4.4 Soil Moisture Validation (EDR)

Approach 1: Field measurements at ARM validation site
Validation of soil moisture estimation results is difficult and even more so if satellite data is involved. The difficulty lies not only in the estimation process but also in the measurements of soil moisture. Several issues are involved in soil moisture measurements. Microwave sensors measure soil moisture in the topmost soil layer (1/10 to 1/4 of a wavelength). At 19 GHz, this layer can be about 0.1-0.4 cm deep. The penetration of the microwave signal depends on soil moisture itself. In view of this, it is difficult to decide the depth of soil samples for in-situ measurements. Soil moisture changes very rapidly in the top layer. In addition, there are practical problems in collecting soil samples at this depth. Also, spatial distribution of soil moisture depends on soil parameters, which are not distributed homogeneously in the area. As a result, average soil moisture computed from point measurements in a footprint area may not be a correct representation of the soil

moisture in the footprint. Close comparison of in-situ measurements from SGP experiment with the VIIRS soil moisture predictions will be attempted, as well as the temporal and spatial comparisons.

6.4.4.5 Surface Type validation (EDR)

Approach 1: POES and EOS comparisons
Using climatic and geographic stratification, the accuracy will be determined for VIIRS surface type. The validation will performed using high and fine resolution remote sensing data such as MODIS, Landsat-7 data and Ikonos data. Ground field survey and airborne data might also be used when necessary.

6.4.4.6 Vegetation Index Validation (EDR)

Approach 1: Ground and aircraft data
The visible and near-IR channel data from ground sensors, such as Spectrometers, Parabola, and airborne sensors, such as MAS and MQUALS will be used over EOS sites to derive vegetation index products. These products will be compared to VIIRS retrievals over several vegetated land surface types

Approach 2: POES and EOS comparisons
The visible and near-IR channels included on the MODIS instrument permit evaluation of narrower (and atmospherically clean) wavebands for use in vegetation indices that might be anticipated to be available from the VIIRS. This study will examine the influence of the use of narrow band visible and near-IR channels on vegetation indices anticipated to be available from the VIIRS. The VIIRS vegetation EDRs will be compared to those available from the present AVHRR sensor for data continuity. Differences in the vegetation indices will be assessed for several vegetated land surface types (IGBP classification). This study should result in i) assessment of the anticipated improvements in vegetation index products from the VIIRS and ii) general guidelines for comparisons of VIIRS-derived vegetation indices, when available, with historical AVHRR-derived vegetation indices. VIIRS EDR data sets for several extended periods will be generated through an annual cycle for the whole globe.

6.4.5 Validation Approaches for Ocean Products

6.4.5.1 Sea Surface Temperature (SST) (Primary EDR)

Approach 1: M-AERI comparisons
Cloud-free and reasonably uniform and temporally stable targets will be selected, with a range of radiance levels encompassing the range of surface temperatures observed by M-AERI and atmospheric water column amounts measured by CrIS.
VIIRS and CrIS SSTs will be extracted along M-AERI cruise tracks within predefined time and spatial intervals. Co-location must be within a few kilometers, and within a few tens of minutes. These conditions may be relaxed in conditions of high wind speed when diurnal changes are muted. Some spatial averaging of the near-surface data should be done

to avoid spurious effects of sub-pixel horizontal temperature variations.
The imagery and the M-AERI time series along track of a moving ship the will be used to characterize the area for which the VIIRS or CrIS SST is considered valid. Quality flags will be assigned to the comparison and are dependent on the variability of the scene. As necessary and appropriate, high-resolution GOES products will be used to characterize temporal change of the scene during the comparison period.

Approach 2: Satellite Radiometer Comparisons
VIIRS and CrIS SSTs may be validated by comparison with satellite-derived SSTs from similar imaging radiometers, such as MODIS, AATSR, GLI and AVHRR that may have a longer and more-established calibration/validation history. If these radiometers have similar spectral responses in the corresponding channels, and are on satellites in orbits close to that of NPP, it may be possible to cross-validate top-of-atmosphere brightness temperatures. Inter-satellite comparison can be done over large areas of cloud-free ocean. Atmospheric radiative transfer modeling may be required to compensate for the differences in the relative spectral response functions and different viewing geometries of the pairs of radiomters.

Approach 3: Validation using sensors mounted on ships and buoys
This has been the first and primary approach for operational uses. In this approach in-situ thermometers mounted at a depth of one to several meters on drifting and moored buoys provide a sub-surface measurement, conventionally referred to as bulk temperature Similarly, thermometers mounted on the hulls and in the engine cooling water intake flow of selected ships can be used if carefully calibrated. At wind speeds greater than ~6m/s, the relationship between skin and bulk temperatures appears to be fairly well constrained, so these data should be restricted to these conditions or during the night. During the day in conditions of lower wind speed, vertical temperature gradients can decouple the bulk measurement from the skin temperature. These factors will be considered in the validation of both the skin and the bulk SSTs.

Approach 4: MAS and NAST-I low altitude aircraft measurements
Low altitude flights of the ER2 and/or Proteus beneath the NPP will be conducted with the NAST-I and MAS. Micro-windows will allow for determination of the SST under minimal atmospheric attenuation conditions.

Approach 5: GIFTS Observations
The GIFTS in geostationary orbit and with very high spatial and spectral resolution will enable measurements of SST coincident with underpasses of the NPP.

6.4.5.2 Ocean Color and Chlorophyll validation (EDR)

Approach 1: MOBY measurements
MOBY data will be used primarily for vicarious calibration of the sensor. The vicarious calibration takes into account the coupled ocean-atmosphere system as embodied in the atmospheric correction algorithm. The current placement of MOBY off Lanai, Hawaii was

selected to provide high quality data in relatively clear and homogeneous water in an area having aerosol properties typical of the open ocean. Also, cloud cover and logistics support facilities (a ship for deployment/retrieval: maintenance and calibration lab facilities) were important considerations. The MOBY spectrometer resolution will provide accurate replication of the VIIRS reflective band passes which is not feasible with typical filter radiometers.

Validation of water leaving radiances will include observations from other locations using a shipboard version of the MOBY spectrometer (off Southern California and Baja, and other cruises) and other commercially available instruments with spectral bands similar to the VIIRS ocean bands. These observations will be “matched” to VIIRS subscenes for direct comparison of derived products. As demonstrated with SeaWiFS, this approach yields a quantitative statistical evaluation of product accuracy, provided adequate quality control criteria, and are applied to both in situ and satellite measurements.

While it is difficult to collect all parameters on all cruises, at least one “initialization cruise” that combines all necessary measurements will be conducted shortly after VIIRS operational data collection begins.

Approach 2: Comparison to POES and EOS products

Ocean Color:

Ocean color products from other satellites, such as MODIS, GLI, POLDER, and MERIS, will be compared to VIIRS products. Such comparisons can be conducted on both global and regional scales to better assess algorithm strengths and deficiencies. It is unlikely that the different missions will use the same atmospheric correction and bio-optical algorithms.

Chlorophyll Products:

Bio-optical algorithms to remotely estimate the concentration of chlorophyll-a and total suspended matter are being developed by the international ocean color community. The SeaWiFS, MODIS, and SIMBIOS programs and the International Ocean Color Coordinating Group (IOCCG) work to foster international cooperation in algorithm formulation, field data collection, and product evaluation, especially in areas that are poorly sampled (e.g., the Southern Ocean). As with the marine optical data, the chlorophyll-a data will be archived in a central bio-optical database where it is available for direct comparison of simultaneous VIIRS retrievals.

6.4.5.3 Net Heat Flux (EDR)

To be included.

6.4.6 Validation Approaches for Snow/Ice Products

6.4.6.1 Sea Ice Characterization Validation (EDR)

Approach 1: Airborne and EOS comparisons

The pre-launch plan for the Sea Ice Age and Sea Ice Edge Motion EDR includes sensitivity studies, analysis of simulated VIIRS data, and verification using MODIS-type data. Observations from AVIRIS, MAS, MODIS, GLI, and AVHRR will be used in the pre-launch phase to study the error characteristics and optimum techniques for the algorithm. It is expected that MODIS validation data will be of great value. This data is expected to include *in-situ* field measurements combined with MODIS observations, MAS underflights, and low level aircraft measurements at spatial resolutions less than 10 meters. This data is then used in combination with the VIIRS sensor model to produce simulated VIIRS scenes, apply to NPOESS/VIIRS Sea Ice Age/Edge Motion algorithms to retrieve EDR products, and compare these results with "truth" derived from *in-situ*, aircraft, and MAS data. Participation of the NOHRSC and ORA, as well as NESDIS/OSDPD and the National Ice Center is planned in this product evaluation, based on the co-located AVHRR and MODIS images, and derived products will be compared from local to hemispheric spatial scales for accuracy and quality. The potential for VIIRS/CMIS data fusion to produce First Year/Multi-year classification and ice edge motion will be studied with the use of MODIS data and Advanced Microwave Scanning Radiometer (AMSR) data.

6.4.6.2 Ice Surface Temperature

Approach 1: Comparison to EOS products

The Government Team will evaluate ice surface temperature data from MODIS with respect to current operational and experimental NWS and NESDIS products, such as those from AVHRR/3. The purpose is to reduce the risk associated with the use of NPOESS/VIIRS products in NESDIS and NWS operations. The benefit of incorporating the additional spectral information available with MODIS in ice surface temperature retrieval procedures will be evaluated, as will the use of new field data. Co-located AVHRR, MODIS and VIIRS images and derived products will be compared from local to hemispheric spatial scales for accuracy and quality. For example, IST products over a variety of North American watersheds, North America and Eurasia, the Northern Hemisphere, arctic and antarctic will be evaluated. Samples of derived products will be made available to NCEP, the National Ice Center, and the scientific community for evaluation. This evaluation process will provide feedback that may lead to modification of the VIIRS algorithms.

Approach 2. In-situ and Airborne Instrument Comparison

In-situ and airborne data will be used in the validation. These data will come primarily from NWS meteorological stations and NPP calibration/validation sites. Reports detailing the methods and results of the evaluation, and recommendations for NPOESS VIIRS proposed designs will be proposed.

6.4.6.3 Snow Cover and Depth Validation (EDR)

Approach 1: *In-situ* and Airborne Instrument Comparison

In-situ and airborne data will be used in the validation. These data will come primarily from NWS meteorological stations and DOE ARM CART sites. Reports detailing the methods and results of the evaluation, and recommendations for NPOESS VIIRS proposed designs will be produced by NOHRSC, CMISS, and ORA. This study will also allow NOHRSC to determine the usefulness of a VIIRS-MODIS ground receiver.

6.5 Planned Validation Approaches for NPP CDR products

6.5.1 Atmospheric Sounding Profile Validation

6.5.1.1 Clear Column Radiance (CDR)

The validation approaches proposed to validate the Clear Column Radiance Fire CDR is the same as the ones proposed for CrIS radiance validation in section 5.2.5.2.

6.5.1.2 Ozone profiles validation (CDR & EDR)

Approach 1: Comparisons to Other Satellites Retrievals
Currently, the available satellite instruments producing ozone products include TOMS, SAGE-II, SBUV-2, HALOE, and MLS. After NPP launch, in addition to CrIS/ATMS, AIRS and SAGE-III will also be producing ozone products. One of the advantages of satellite based calibration is the availability of a large number of observations at periodic time intervals. The lifetime of the AIRS instrument on the Aqua platform is expected to overlap with that of NPP. AIRS will be producing similar ozone products on a global scale that will continue after NPP launch. This makes it a perfect candidate for cross-instrument calibration. Except for differences in the temporal and geographic position of the retrieved profiles, that needs to be accounted for, the ozone products from AIRS and CrIS/ATMS are readily comparable and can be used for calibration of CrIS/ATMS. Longer-term trends and instrument degradations can also be determined using AIRS data.
Total column measurement of ozone is currently measured from space through the TOMS series of instruments (EP-TOMS currently on the Earth Probe satellite and on the QuikTOMS platform). An indirect measure of the tropospheric column is possible by subtracting an integrated stratospheric profile from SAGE-III, from a total column. These calibration methods will be of less importance with the successful operation of AIRS.

Approach 2: Comparison to In-situ data
Ozonesondes have been a standard instrument for measuring ozone from the ground to the lower stratosphere. A long-term measurement database exists (as long as 35 years for some sites), mostly within the Northern Hemisphere mid-latitudes, on a roughly once-a-week basis. Ozonesondes measurements offer good precision and excellent vertical resolution (about 150 m), although results become more uncertain above 25 km because of inefficiencies in pumping mechanisms, and corrections may be needed to SO_2 interference. For NPP, the major difficulties are the comparatively low geographical and temporal density of ozonesondes measurements. In addition, comparison to ozonesondes should be

only done for near-simultaneous measurement and clear skies. It is not known if there will be enough routine ozonesonde measurements satisfying these conditions for a statistically significant validation.

6.5.1.3 Precipitation Rate Validation (CDR & EDR)

Approach 1: NEXRAD Precipitation Data
By definition of CPR, the prime validation source must be coincident NEXRAD data (offsets < 5 minutes), with emphasis on the eastern United States where the NEXRAD network has more complete coverage. The NEXRAD data must be convolved with a response function characterizing the appropriate 15- or 50-km antenna pattern. Radars operating at other frequencies and global locations will provide secondary validation. Snow pillows can provide more accurate ground truth for snowfall retrievals (water-equivalent mm/h).

Approach 2: BALTRAD Precipitation Data
BALTRAD radar data available for the Baltic region will be used in conjunction with Snow/Ice cover maps to derive precipitation data. Radar data will be convolved to the spatial resolution and observation geometry of the ATMS. Probability of detection as function of the precipitation intensity will be derived. The precipitation screening algorithms will be adjusted according to findings.

6.5.1.4 Trace Gasses Validation (CDR & Application)

Approach 1: Comparisons to Other Satellite Observations
AIRS/AMSU/HSB, a sounding instrument suite that will also be in orbit at the time of the NPP mission, will be making similar IR/MW measurements with the ability to retrieve trace gas abundances. When these abundances become validated AIRS products, they will be ideally suited to validate the CrIS/ATMS trace gas products. Both data sets will be global in coverage and offer many data points at varied conditions to extensively validate the trace gas product. Due to the political and social impact of CO_2 there are measurement campaigns in the planning stages. They will focus on CO_2, CH_4, and CO *in-situ* measurements and can be used to validate the AIRS and CrIS products.

6.5.2 Validation Approaches for Aerosol Products

TBD

6.5.3 Validation Approaches for Cloud Products

6.5.3.1 Cloud Ice Water Validation (CDR & EDR)

Approach 1: EOS and POES comparisons
NOAA AMSU operational cloud ice water /particle size algorithm retrieves both IWP and particle effective diameter. These products are derived for thick ice clouds including

precipitation conditions. Since ATMS has two channels similar to AMSU, the algorithm can be modified and tested with NPP ATMS and CrIS.

Approach 2: Aircraft comparisons
Calculations of high-spectral resolution infrared radiances in cirrus cloud situations indicate that cloud forcing (clear minus cloudy) spectra are sensitive to ice particle size, ice water path, and cloud altitude. A numerical procedure based on the DISORT algorithm is used to retrieve the effective radius and ice water path of cloud layers with known optical depths and cloud boundaries and with nearby clear sky atmospheric conditions also known. The reasonable reproduction in a rather wide window region suggests that the DISORT based algorithm can distinguish small from large particle clouds as well as provide a fair estimate of IWP. Ice particle size and ice water path are estimated with 20% variation in the inferred values.

6.5.3.2 Cloud Liquid Water Validation (CDR & EDR)

Approach 1: EOS and POES comparisons
NOAA AMSU operational algorithm retrieves both CLW and TPW. It is a physical retrieval algorithm which uses two AMSU primary channels at 23.8 and 31.4 GHz. These two frequencies are identical to ATMS channel selection. The algorithm can be directly modified for ATMS applications. Comparisons between VIIRS and ATMS retrievals are also planned.

Approach 2: Aircraft comparisons
Calculations of high-spectral resolution infrared radiances in cirrus cloud situations indicate that cloud forcing (clear minus cloudy) spectra are sensitive to ice particle size, ice water path, and cloud altitude. A numerical procedure based on the DISORT algorithm is used to retrieve the effective droplet size and water path of cloud layers with known optical depths and cloud boundaries and with nearby clear sky atmospheric conditions also known. The reasonable reproduction in a rather wide window region suggests that the DISORT based algorithm can distinguish small from large droplet clouds as well as provide a fair estimate of LWP.

6.5.4 Validation Approaches for Land Products

6.5.4.1 Atmospherically Corrected Reflectance Validation (CDR)
Land surface reflectance
To be included.

6.5.4.2 Active Fires (CDR & Application)

The validation approaches proposed to validate the Fire Area and Temperature CDR are the same as the ones proposed for Fire Area and Temperature EDR in section 6.4.4.5.

6.5.4.3 LAI and FPAR validation (CDR)

Approach 1: Field measurements at EOS validation site
Generally, LAI or FPAR can be derived from hand-held instruments (including hemispherical view cameras) which assess light obscuration by vegetation canopy or crown. The instruments typically employ a modified form of Beers' Law to derive LAI or FPAR units. To determine LAI or FPAR at a plot scale, an investigator typically collects many samples over an area, then attempts to scale these "point" measurements to a larger area using fine-scale satellite or aircraft imagery. Although there is no current standard technique for either spatial sampling design or scaling, an LAI focus group under the auspices of the CEOS WGCV Land Product Validation Subgroup is developing a "Best Practices" handbook. Although historically the field instrumentation assumed a homogeneous distribution of leaf material, newer instrument specifically assess canopy clumping and reportedly produce superior results. In deciduous areas, "leaf drop baskets" are sometimes deployed to determine the LAI via the autumn leaf fall. Comparatively few FPAR validation studies have been conducted to date, and thus even fewer standards currently exist. Proper measurement requires measurement of four radiation fluxes upwelling and downwelling above the canopy, and the same between the canopy and the soil. Further, some canopy-absorbed PAR radiation is attributable to non-green leaf, stem or standing dead material; accurate FPAR measurements require knowledge of these quantities.

6.5.5 Validation Approaches for Ocean Products

6.5.5.1 Sea Surface Temperature (CDR)

The validation approaches proposed to validate the SST CDR is the same as the ones proposed for SST EDR in section 6.4.5.1.

6.5.5.2 Ocean Color (Water Leaving Radiance) (CDR)

Approach 1: Validation using MOBY data
Automated collection of MOBY data at the time of VIIRS overpasses, and MOS data during MOBY servicing cruises will be used, and a matchup data base to sample a useful range of VIIRS swath and sun angles will be developed. The overall approach for MOBY is discussed by Clark and Mueller in Chapter 11 of the Revised SeaWiFS Protocols for Calibration/Validation. Multiple radiometer buoys are maintained, and are deployed sequentially for three month intervals. The measured spectral response function of the satellite sensor is convolved with the high resolution spectrometer data. Upwelled spectral radiances are collected at 3 depths and propagated to and through the surface to produce the desired water-leaving radiance values which are compared with the values retrieved from the satellite sensor.

MOBY data will be used primarily for vicarious calibration of the sensor. The vicarious calibration takes into account the coupled ocean-atmosphere system as embodied in the atmospheric correction algorithm. The current placement of MOBY off Lanai, Hawaii was selected to provide high quality data in relatively clear and homogeneous water in an area having aerosol properties typical of the open ocean. Also, cloud cover and logistics support facilities (a ship for deployment/retrieval: maintenance and calibration lab facilities) were important considerations. The MOBY spectrometer resolution will provide accurate replication of the VIIRS reflective band passes which is not feasible with typical filter radiometers.

Validation of water leaving radiances will include observations from other locations using a shipboard version of the MOBY spectrometer (off Southern California and Baja, and other cruises) and other commercially available instruments with spectral bands similar to the VIIRS ocean bands. These observations will be “matched” to VIIRS subscenes for direct comparison of derived products. As demonstrated with SeaWiFS, this approach yields a quantitative statistical evaluation of product accuracy, provided adequate quality control criteria, and are applied to both in situ and satellite measurements.

While it is difficult to collect all parameters on all cruises, at least one “initialization cruise” that combines all necessary measurements will be conducted shortly after VIIRS operational data collection begins.

Approach 2: Other In-water radiance measurements
A variety of instrumentation and protocols to make individual and time series of water-leaving radiance and also above water reflectance measurements from ship, moorings, drifting buoys, and permanent platforms have been developed. Details can be found at the SIMBIOS web site. These measurements, most by independent investigators, are very important for validation of the global water leaving radiance signals following initialization at the MOBY site.

Approach 3: Validation using aircraft sensors
Use of aircraft sensors for validation of water-leaving radiances is primarily in the area of providing improved spatial variations and coverage. Maintaining sufficiently accurate absolute uncertainty of the instrument and its atmospheric correction for use in direct validation of water leaving radiance has improved significantly over the past decade, however. Aircraft sensors show great utility in validation of bio-optical properties, but cannot provide the high degree of accuracy of in-water or shipboard observations at this time.

7 Data Processing Support for Calibration, Quality Assessment and Validation

7.1 Calibration, Quality Assessment and Validation

The performance of the NPP products produced by the IDPS, SDS and direct broadcast systems will be ensured through calibration, quality assessment (QA) and validation activities. These three activities are interrelated and are summarized again below to assist in understanding the quality assessment implications.

Calibration: define the transformation of sensor digital numbers (DN) to radiance in a traceable manner

- An operational activity which utilizes on-board measurements (internal blackbodies, space views and spectral sources) and coefficients to transform digital numbers to radiance units. In addition, some corrections might be applied to the radiances, such as transformation to a standard frequency, correction to a standard instrument response function, polarization corrections, etc..
- Calibration data are stored as per detector, scan line, focal plane etc. These data are attached to the product as metadata.
- Coefficient tables are generated from pre-launch measurements, knowledge of instrument characteristics, post-launch measurements (e.g., deep space look), and vicarious calibrations. The associated data sets used to determine the calibration coefficients must be archived.

Quality Assessment: evaluate and document product quality with respect to the intended product performance (Roy *et al*., 2001)

- A near-operational activity that is performed routinely.
- QA is typically performed by subjective examination of products in the absence of inter-comparison with other data.
- QA results are stored in the product as per-pixel QA flags and QA metadata (written in the production code and retrospectively) (Lutz *et al.* 2000).
- QA metadata are used to flag individual product granule quality (e.g. granule X = ‘Failed QA’) and to document issues that need rectification.
- QA results are examined to ensure that poorly performing products are not validated or are validated appropriately.
- Users may query QA metadata as part of the data order & browse process.

Validation: quantify product accuracy over a range of representative conditions (Justice *et al*., 2000, Morisette *et al*., 2001)

- This activity is not operational but typically periodic/episodic.

- It is usually performed by comparison of products with other data that have known uncertainties.
- Results are published in the literature years after product generation.
- Validation results define error bars for the entire product collection and are not intended to capture artifacts and issues that may reduce the accuracy of individual product granules.

It is recognized that calibration, validation, and QA activities overlap and different instruments may have different capacities for these. For example, ocean products may be compared with buoy data in a near operational manner providing a routine validation.

There is a strong linkage between the results of near-operational calibration and QA with algorithm updates. This has implications for configuration control and oversight (particularly with respect to the incentive mechanism for updating the IDPS algorithms).

7.2 NPP Data Approach

The NPP data approach attempts to assure consistency of data requirements across subsystems and releases and to support the data standardization necessary for total system inter-operability within a heterogeneous open systems environment. The NPP data approach strives to ensure that calibration, quality assessment and validation activities can be performed, and product granules can be retrieved to support these NPP activities in an efficient and reliable manner:

- File names allow product granules to be uniquely identified. For example, filenames include the sensor acquisition date and time, production date and time data; CDR file names include grid/geolocation information.
- File names indicate the place of production: IDPS, SDS or direct broadcast.
- Products include per-pixel quality and processing history information (these should be propagated appropriately between products).
- Products carry input pointer metadata recording which upstream products were used to make the specific product granule.
- Products carry sufficient metadata (e.g., temporal, spatial, cloud cover) to allow flexible and efficient browse and ordering of the product archive [recognizing that cloud cover definitions may not be available or applicable for certain products].
- Product version information is reflected as metadata and preferably in the product file name (both IDPS and SDS products).
- Products carry quality and maturity metadata that may be set after production.

7.3 Production System Support for Calibration, Quality Assessment, and Validation

The IDPS, SDS and direct broadcast NPP product systems have different algorithm and production specifications. These systems will support the rapid and efficient processing of products and product subsets / subsamples, and reprocessing where applicable, for calibration, QA and validation activities.

7.3.1 Interface Data Processing Segment (IDPS)

The IDPS

- produces near-real time, high-quality operational products within 90-150 minutes (TBR) (NPP) & 20 minutes (NPOESS)
- does not reprocess data for operational routine products but has significant speed/storage margins.
- produces RDRs, SDRs & EDRs.
- requires capacity for SDR & EDR spatial subsetting (e.g., VIIRS) and subsampling (e.g., CrIS).
- requires capacity for automated delivery of data subsets and subsamples to a dedicated archive.
- requires capacity to project EDRs into a variety of Earth based coordinate systems
    - geolocation accuracy of IDPS products may not be as high as SDS products and may not be sufficient to meet validation and QA co-registration needs (TBD).
    - access to SDS updated interior & exterior orientation estimates is recommended or capacity to improve retrospectively the geolocation of IDPS products by image matching.

7.3.2 Science Data Segment (SDS)

The SDS

- is not a near-real time production system, reprocessing allowed.
- produces science high quality Level 1A/B, CDRs and higher products.
- has internal archive to support the SDS Science Team's calibration, QA and validation requirements.
- requires capacity for spatial subsetting (e.g., VIIRS) and subsampling (e.g., CrIS) of Level 2 and Level 3 CDRs.
- requires an SDS geolocation product with sufficient accuracy to enable production of temporally composited CDRs and to meet Level 2 CDR product validation and QA co-registration needs.
- requires automated delivery of data subsets and subsamples to a dedicated no-frills archive (e.g. an anonymous ftp site). This should be part of the SDS archive.

7.3.3 Direct Broadcast System

During normal science operations, NPP will continuously transmit real-time data from all three instruments to line-of-sight ground stations via an X-band direct broadcast system. This direct broadcast capability will offer important benefits, for example:

1. It will provide rapid access to NPP instrument data for time-critical applications.
2. It will act as temporary backup to the stored-and-down-linked data.
3. Direct broadcast data processing systems provide a means to quickly modify and test improvements to the data processing algorithms and stage them for dissemination to the general public.

The NPP In-Situ Ground Segment (NISGS) at the NASA GSFC will be responsible for developing a prototype, stand-alone test-bed system to acquire the direct broadcast data and generate instrument – specific Level 0, Level 1 and selected higher level data products. As the interface between the NPP “mainstream” components and the direct broadcast user community, the NISGS project will provide users with all the necessary software, documentation and information corresponding to the establishment, acquisition and processing of NPP direct broadcast satellite data.

The NPP *In-situ* Data processing System (NISDS) will incorporate the scientific calibration parameters and algorithms developed by the SDS in a real-time, stand-alone mode. Selected Level 2 and higher science algorithms will also be developed. The end-to-end system, from the X-band broadcast electronics on board the spacecraft through the output of the Level 1B processing, will be validated by comparison of the geo-located and calibrated Level 1B radiances from the direct broadcast data with those obtained by the SDS using the stored-and-down-linked data. The comparisons will be done using the same data sets used for the validations in this document. Validation of those higher level products for which it makes sense (i.e., which are not sensitive to the differences between the SDS and NISDS algorithms) will also be done by comparison.

The SDS and NISGS will work together to validate the data products obtained using the processing system at the NASA GSFC Direct Readout Laboratory (DRL). It is envisioned that other direct broadcast users will validate their systems against the DRL system.

7.4 Archive and Distribution System Support for Calibration, Quality Assessment, and Validation

The NPP archive and distribution systems will support the rapid and efficient retrieval of products for calibration, QA and validation activities. In addition the NPP archive and distribution systems will support the documentation of product performance information as a result of calibration, quality assessment and validation activities. These information data are required by production personnel and algorithm developers to identify products that are performing poorly so that improvements may be implemented. These information data are also required by the product users.

7.4.1 Archive & Distribution Segment (ADS)

The ADS

- archives all IDPS & SDS products.
- enables public and Science Team access.

- requires capacity to support SDS reprocessing assuming it has sufficient resources to enable retrieval of products (RDRs, SDRs and EDRs).
- has sufficient distribution capacity to support Science Team routine product QA (scoped at 10% daily production volume).
- has capability to restrict public access by product, production date and product version

7.4.2 SDS archive

The SDS Archive

- archives RDRs sent from the IDPS, SDS products, and certain IDPS EDRs retrieved from the ADS for validation purposes.
- allows Science Team access only.

7.4.3 ADS and SDS Archive Requirements

The ADS and SDS Archive requirements include

- Ftp pull/push of products.
- Media (CD-ROM, DVD, DLT, SDLT etc.) product distribution. (SDS will support media generation for only a fraction of the total products generated (5 percent).
- Interactive web-based browse/ordering interface to support.
    - searching against all metadata using boolean and relational operators
    - searching against multiple metadata using logical operands (AND, OR)
    - browse imagery
    - on demand spatial (and spectral ?) subsetting
    - coincident searching of data from different sensors (e.g., VIIRS product acquired spatially and temporally coincident with Landsat, e.g. spatially and temporally coincident NOAA N', ATMS, CriS, VIIRS data)
- Subscription based access
    - triggered by metadata ingest
    - optional email notification
    - ftp push/pull or media distribution
- QA metadata update. QA metadata may be set with a default value and defined retrospectively by registered QA personnel at any time after product generation. Recommend update mechanism based on an email fixed format supporting (i) linked list of product file names and corresponding QA metadata values, (ii) summary product filename, version and production range information to be set with common QA metadata.
- Archive of field measurements, aircraft and ancillary validation data sets is recommended as well as distribution in facilities that are independent of the ADS and SDS archives. Recommend use existing systems (e.g., SYMBIOS, Oak Ridge DAAC) and note that may need to ensure the continuity of some of these systems.

7.5 Validation Data Set Needs and Management

There are several varieties of validation data associated with a flight project that must be systematically collected, formatted, documented, and archived. These activities must be an integral part of the project calibration and validation program design, including dedication staffing and computer system resources. The documentation should be developed as the data are generated, otherwise important details are sure to be lost. The data sets can be categorized as follows:

1. prelaunch sensor calibration and characterization data (laboratory data including calibration source traceability to NIST standards),
2. mission simulation data (either derived from existing heritage data or modeled) with generation code used to test processing system performance and prototype quality assessment procedures,
3. on-orbit calibration and sensor performance data (e.g., internal lamps, blackbody sources, solar diffuser, lunar imaging data),
4. *in-situ* vicarious calibration data (e.g., surface radiance, Marine Optical Buoy),
5. *in-situ* product validation data (e.g., field data for match up comparisons of derived products and for atmospheric correction validation),
6. higher spatial resolution satellite data used as a surrogate for "truth" with measured uncertainties (e.g., used to "validate" active fire and snow products),
7. measurement protocol experiment and calibration round robin data (laboratory or field data collected to test the accuracy of a particular measurement approach or calibration source).

Items 2 and 7 may not be typically considered as part of a mission, but experience with missions such as SeaWiFS and MODIS has shown that they are indeed critical elements of a comprehensive validation program.

Documentation should include a description of the methodology or measurement protocol followed during data collection as well as appropriate metadata (time, location, units, etc.). *In-situ* data, on-orbit calibration data, and the corresponding match-up satellite subscenes may be best maintained within the project where the calibration and validation staff resides. These data require specific expertise in their quality control and analysis. The match-up subscenes should be extracted at Level 0 so that the data is extracted only once, as revisions to the Level 1 and 2 processing are certain. The archival of the *in-situ* data must be handled through a relational database that allows the data to be queried and extracted in a variety of ways. Therefore, database management is an additional staffing requirement. In the case of SeaWiFS, the calibration and validation staff also handles the validation databases. Finally, it is desirable for the external community to have access to the *in-situ* data and a data policy that details the staged release to national archives such as the National Ocean Data Center and acknowledgment requirements should be outlined in advance.

Product-specific guidance to validation scientists on what constitutes a representative and acceptable minimum validation is required. Broadly the location and timing of validation data define this and should encompass:

- the full range of the geophysical parameter
- a range of representative surface, atmospheric and acquisition conditions
- locations/times where the product generation algorithm is known to be sensitive to exogenous factors

7.6 Examples of Validation Data Supporting QA System

A number of examples of how to utilize numerical weather prediction (NWP) products and systems for QA and validation are now discussed. These techniques have proven to be useful for QA and validation on heritage instruments.

Radiance and EDR QA using NWP analysis products:

A very useful approach to validate CrIS and ATMS radiances is to compare them with radiances simulated from NWP analysis fields. Analysis fields of temperature, moisture, and ozone are spatially and temporally interpolated to selected CrIS and ATMS FOV's. Radiances are computed using a fast radiative transfer model from the interpolated atmospheric state. The enormous sample size provides the means to study and monitor scan dependent bias and standard deviation between measured and computed radiances. Time series of channel bias and standard deviation are updated daily. This capability will quickly detect apparent outliers and will also detect sensor drift.

Differences between EDR and analysis fields provide very useful information about the quality of the retrieval. Large differences may indicate problems in the retrieval. Coherent patterns may also indicate problems in the forecast. Further inspection using campaign data or operational radiosondes will determine if the problem is in the EDR or in the analysis. Further confirmation can be achieved by comparing EDR fields from other sensors (e.g. AIRS, IASI, ATOVS). Differences as a function of view angle will allow detection of scan dependent errors.

Assessment of EDR's using data-assimilation:

The SDR/Level 1B radiances or EDR/CDR products can be used in an assimilation system to assess the information content in the EDR's via data assimilation. In data assimilation the instrument measurements are used in an analysis with other measurements and a forecast model to adjust the model. A large quantity of measurements (usually more than 1 month) is required to perform this test. The information content of the EDR's is evaluated by comparison of the forecast quality with and without assimilation of the EDR's.

Radiance and EDR validation using operational radiosondes:

Ensemble statistics of radiance residuals (bias and standard deviation) from radiance simulated from operational radiosondes provides a model independent validation. Approximately 300 matchups (collocated radiosonde and satellite FOV's) are available each day. Operational radiosondes should not be used for spectroscopy validation; however, they are a very good source for long term monitoring. The matchups can also be used to determine coefficients for radiance tuning. Knowledge of radiosonde type is important in assessing instrument quality. Radiance residuals need to be analyzed as a function of radiosonde instrument type.

Similarly, EDR error using operational radiosonde provides a model independent validation. Temporal and spatial filtering is used to ensure that the radiosonde location and time is similar to the CrIS/ATMS EDR. Monitoring of EDR accuracy provides long term monitoring. Approximately 300 matchups are collected each day.

Radiance QA using eigenvector decomposition:

Eigenvectors of radiances can be used to monitor radiance quality. This is achieved by reconstructing radiances using a truncated set of eigenvectors. The reconstructed radiances are compared with observed radiances. If the difference is very large then the radiance quality may be questionable.

Regeneration of EDRs using ancillary data:

One approach for detecting possible inadequacies in EDR algorithms is to regenerate the EDR with different initial conditions. For example, a CART site may show that the Level 1B data is of high quality, but the EDR is not. To test if the problem is due to the algorithms sensitivity to the initial surface emissivity the EDR could be regenerated using the emissivity measured at the CART site. Hence, the capability to regenerate retrievals using a diagnostic algorithm can be very important.

Appendix A: Overall Approach to Calibration and Validation

A.1 Pre-flight Instrument Testing and Characterization

Pre-launch instrument characterization will be the responsibility of the vendors for the NPP instruments. As part of the shared responsibility, the Government Team will work closely with the vendors during the pre-launch testing and characterization to assure that the post-launch instrument performance is understood and radiances are suitable for assimilation (See Section 4 for details on this effort). The Government Team will provide advice to the IPO and thereby to the vendors on sensor level requirements realization and characterization/calibration procedures. The Government Team will work with the SSPR contractors to assure that the sensors are fully characterized during the development and pre-launch phase and calibrated with NIST-traceable standards and procedures at thecomponent, sub-system, instrument and spacecraft levels prior to launch. The Government Team will conduct coordinated analyses of the data and instrument trending during the NPP mission, and share these results with the IPO and the sensor vendors in a timely manner. Details of the work split among the participants will be delineated in subsequent versions of this plan.

The Government Team will have NASA and IPO components for these calibration and validation activities:

> The NASA GCST will manage an NPP Calibration Support Team (NCST) modeled after the successful MODIS Calibration Support Team (MCST). This group will work under the direction of the NASA NPP Project Scientist to develop research quality Level 1B data products from VIIRS, CrIS, and ATMS data. The NCST will help determine the needs for characterization and calibration in concert with the GCST that will be developing selected Level 2 and higher data products (CDRs).
>
> The IPO will manage an NPP Calibration/Validation Support Team based on the IPO Science Team, the IPO System Engineering and Test & Evaluation Teams and the IPO Product Teams. This group will work under the direction of the IPO NPP Project Scientist, supported by the IPO System Engineer. The purpose of the IPO Calibration/Validation Support Team is to help determine the needs for characterization, calibration and validation of products as well as to ensure the development of high quality RDRs, SDRs and EDRs from the NPP VIIRS, CrIS, and ATMS data for possible operational utilization in the NPP era and the operational utilization in the NPOESS era.

Finally, the Government Team will develop methods to report their results. At minimum this should include regular workshops including SSPR, the Government Team, validation scientists and the user community, a plan for immediate posting of known issues and results as they become available, and regular hard-copy reports.

A.2 Calibration Monitoring and System Verification

The NPP sensors have provision for on-board calibration. In most cases, on-board calibration is better than vicarious calibration. However, the accuracy and stability of instrument RDRs and SDRs depend on the specific approach to monitoring and implementing on-board calibration. Moreover, in rare cases, on-board calibration systems can fail. Thus, the Government Team should work with the SSPR to develop a suitable calibration implementation plan (e.g., the frequency of calibration maneuvers or lunar looks and calibration table updates). Further, the Government Team should work with the contractor in verifying and debugging the on-board systems and data sets. The Government Team should include the expertise to vicariously verify or replace on-board calibration. Historically, this has been accomplished through high altitude aircraft under-flights and monitoring of well-instrumented and stable calibration field sites.

For the sounders, radiative transfer calculations are also used to calibrate at-sensor radiances.

Geolocation, band-to-band registration, PSF, other instrument system checks will require pre-launch and post-launch testing as discussed in sections 4 and 5.

A.3 Quality Assessment and Trend Analysis of SDRs and EDR/CDRs

Early in a typical satellite mission, significant information on algorithm behavior is developed through trend and basic image analysis of the SDR/Leve 1B and EDRs/CDRs. The Government Team must plan to conduct these activities, particularly given the ramp-up schedule for SSPR EDR delivery and implementation. A successful model for such assessment is the MODIS LDOPE facility, which monitors and detects potential algorithm or instrument behavior problems, and investigates and communicates potential problems reported by product users.

A.4 Uncertainty Determination of EDR/CDRs and Intermediate Products

To validate global atmospheric and surface products derived from NPP data, an independent sampling of the global variability of the products is necessary. The expense and effort required to independently measure each variable over the possible range of environmental conditions is significant. The following sections, and their associated appendices, suggest existing infrastructure and facilities available for cost-effective validation.

A.5 Components of the Cal / Val Effort

Land Surface Test Site Networks

As outlined above, NPP validation will include focused field and aircraft campaigns in specific locations and under specific environmental conditions, but also include collection of long time series of selected measurements field or ocean site networks. The framework for identifying and stratifying field site capabilities follows the Global Hierarchy of Observation Surface Types developed by IGBP and adapted for the EOS MODIS Land Team (Table A-1).

Table A-1 describes the tiers and provides examples. This categorization yields an inverse degree of measurement intensity per site with number of sites in the tier. NPP land validation will rely on few intensive field campaigns but a large number of sites for which only satellite scenes are regularly. One deviation in this scheme is the Tier 5 (instrument calibration sites) which is primarily for radiometric calibration.

Table A-1: EOS MODIS Land validation hierarchical test site scheme

Tier	Approx. Number of sites	Sample Area (km^2)	Characteristics	Example Sites/Network
1. Intensive Field Campaign Sites; International Field Campaign Programs	5	1,000	Intensive sampling of all relevant land and atmospheric parameter; often over land cover gradient	FIFE, BOREAS, HAPEX-Sahel, SAFARI 2000, LBA
2. Fully instrumented Sites	5	100	Full suite of radiation and flux measurements; ground, tower and aircraft measurements	ARM/CART Sites
3. Biome Tower Sites	20-30	100	Long term, select instrument packages for process studies; ground and tower measurements; all major ecosystems and climatic regions	FLUXNET Sites
4. Globally Distributed Test Sites	60	25	Limited surface and atmosphere characterization, select instrument suit at different sites; widely distributed variable sampling frequencies (intermittent to continuous) capture seasonal or interannual variability, climatology; permanent site	LTER, NOAA CMDL, BSRN and SURFRAD networks; MOBY Ocean Buoys
5. Instrument Calibration Sites	<5	10	Well-instrumented for vicarious calibration; unique reflectance and emittance properties of uniform, typically non-vegetated surfaces; ground and aircraft measurements may include geometric calibration site(s)	White Sand, Railroad Playa

Many global site networks currently exist, as do many field sites, which are currently not affiliated with any global network. A list of suitable site networks was provided in Table 6-1 and is described in detail in Appendix G.

The calibration and validation of NPP reflective and emissive bands will be based on measurement data sets from the AERI network at the ARM sites, EOS sites, and MOBY/MOCE sites.

ARM Sites (Atmospheric Sounding)

The ARM Southern Great Plains (SGP) site will have five AERI instruments; ARM North Slope Alaska (NSA) and ARM Tropical Western Pacific (TWP) will each have two AERIs. These are zenith-viewing instruments. The calibration accuracy of AERI instruments is NIST traceable. In addition to the ARM sites, NPP cold scene (<270 K) calibration will be validated using P-AERI ground based measurements at the South Pole. P-AERI may be pointed upward to view zenith or downward to view surface or any angle in between. Because atmospheric water vapor concentrations over the South Pole are typically small (~5% relative humidity), slant path effects on NPP and P-AERI window band measurements will be small (<0.5°C). Importantly, P-AERI is capable of viewing the snow surface at the South Pole using the same viewing geometry as NPP. This will minimize surface effects on the calibration validation exercise.

Performance comparisons with products from other platforms are also planned. NPP cloud mask algorithms will be compared with those developed for AVHRR/HIRS on POES and ASTER/CERES/MISR/MODIS on Terra. Atmospheric profiles will be compared with those from HIRS, GOES, AIRS/AMSU/HSB/MODIS, GIFTS, and IASI/AVHRR. Cloud properties will be intercompared with those derived from HIRS, CERES, MISR, MODIS. Aerosol optical thickness and particle size retrievals from NPP will be compared to MISR and MODIS analyses as well as to AERONET measurements. Precipitable water vapor measurements will be compared to (i) radiosonde measurements over the continents, (ii) AERONET-derived column water vapor analysis, (iii) ground-based GPS soundings, (iv) ground-based microwave radiometer measurements at the ARM sites, (v) ground-based Raman lidar measurements at the SGP CART site, and (vi) periodic differential absorption lidar measurements from the DC-8 aircraft (LASE).

EOS Land Validation Core Sites (Land and atmospheric characteristics)

The EOS Land validation Core Sites are being used for MODIS/ASTER Land validation program, and will provide the science community with timely ground, aircraft, and satellite data for NPP science and validation investigations. The sites, currently 24 distributed worldwide, represent a large range of global biome types, and roughly comprise the area within 100 km radius of a center point.

In most cases, each EOS site includes a fixed tower on which above-canopy instrumentation will be mounted to provide near-continuous sampling of canopy-scale radiometric and meteorological variables. A conceptual model for a core site instrument package includes a CIMEL™ ground and sky-scanning sunphotometer (surface reflectance, vegetation index, BRDF), albedometers (albedo), and a CO^2 flux system. These data are augmented by surface measurements of LAI and FPAR at less frequent time intervals. Core Sites will receive priority deployment of validation instrumentation and cover each major biome type delineated in NPP operational and science algorithms.

Ocean Test Sites

The validation will be carried out principally using the Marine Optical BuoY (MOBY) and the Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) instruments, using MOCE (Marine Optical Characterization Experiment) sites off Hawaii (http://orbit-net.nesdis.noaa.gov/orad/mot/moce/index.html), the initialization cruise off Southern California and Baja, and other cruises [TBR].

The role of Ocean Test Sites encompasses the somewhat conflicting needs for intensive validation and initialization data collection, oceanic process studies, time series stations, as well as providing for stratified global observations. Data collected at the time series sites are necessary to validate trends detected in satellite data, and to monitor the response of marine ecosystems and SST to climate change. By including physical and biogeochemical observations, the sites will provide insight on the mechanisms of coupling between biological and physical systems. Data collected at the test sites will be of value to NPP instruments as well as to MODIS, MISR, ASTER, and CERES on the EOS AM-1 Platform, and other missions (SeaWiFS, ADEOS I and II, and METOP).

The scientific objectives of the ocean validation effort are to provide data necessary for the initialization of some product algorithms, and for an ongoing effort to describe the uncertainty fields of the NPP ocean products. This information will be used to identify and remove systematic biases in the data products resulting from the instrument, the algorithms, and data production.
The specific products that require validation are:

- Fundamental radiance products (water-leaving radiance in the visible and surface emittance in the thermal infrared).
- Products relating to the physical and bio-optical state of the water (sea-surface temperature, phytoplankton pigment concentration, chlorophyll a concentration, phytoplankton fluorescence, photosynthetically active radiation, suspended solids concentration, organic matter concentration, coccolith/calcite concentration, ocean water attenuation coefficient, total absorption coefficient, gelbstoffe absorption coefficient, aerosol optical thickness, and phycoerythrin concentration).
- Higher-level products (ocean primary productivity, chlorophyll fluorescence efficiency).

Several fundamentally different, but complementary, data sets are necessary to provide an adequate sampling of the marine atmospheric conditions, oceanic bio-optical state, and sea-surface temperature (SST), needed to validate the NPP Ocean Products. Our validation strategy is multi-fold: Highly-focused field expeditions using state-of-the-art calibrated in-water and surface spectral radiometers, supported by extensive instrument suites to determine the state of the atmosphere, are utilized to understand the atmospheric and

oceanic processes that limit the accuracy of the derived bio-optical properties and the SST. A permanent buoy-based oceanic optical station should be maintained to continuously monitor the performance of the NPP system (sensor plus algorithms).
Long-time period, global-scale data sets are obtained to provide a monitoring capability for revealing calibration drift and the consequences of sudden or extreme atmospheric events, such as volcanic eruptions, transoceanic transport of terrestrial aerosols, cold-air outbreaks, etc., on the global products. These data sets will enable NPP ocean products to define the uncertainties in products under a variety of conditions as well as provide the information required to fine-tune corresponding algorithms.

The *in-situ* observations have been developed with the recognition of their relevance to missions of similar ocean sensors (i.e., SeaWiFS, OCTS, GLI, MERIS, GOES, AVHRR, MODIS).

The approach to validation of the NPP Ocean Products is to compare surface- or *in-situ* -measured values with NPP ocean products. The comparisons will be completed for a variety of situations ranging from those for which the performance of the individual algorithm is expected to be excellent to situations for which the performance is expected to be severely degraded.

For the visible products (bio-optical products and water-leaving radiance), the validation begins with initialization of the sensor, i.e., the process of carrying out on-orbit calibration for a newly-launched sensor, prompted by the fact that it is reasonable to expect that the stresses associated with launch may alter radiometric calibration, using a prediction of the radiance expected at the sensor, based on a rigorous set of *in-situ* atmospheric measurements and radiative transfer computations. On this basis, the sensor calibration is revised to provide agreement with the predictions.

Aircraft Remote Sensing

Aircraft provide opportunities to sample fairly large areas with well-characterized and calibrated instrumentation. Historically, aircraft have been used extensively both independently and in conjunction with field measurements. Many commercial and research-grade instruments are available to provide accurate samples of at-sensor radiances. In most cases, these instruments are significantly different than satellite sensors. Further, the aircraft may fly at low altitudes – well within the troposphere. Thus, sensor-specific algorithms (including atmospheric correction and scaling) or conversions are necessary to derive NPP EDR-equivalent values.

A notable exception is NASA's Airborne Science Program (http://www.dfrc.nasa.gov/airsci/), which provides airborne platforms to carry NASA sensors such as the Airborne Visible Infrared Imaging Spectrometer (AVIRIS), and Earth Observing System (EOS) sensor simulators, such as the MODIS Airborne Simulator (MAS), MODIS/ASTER Airborne Simulator (MASTER), and the Airborne Multi-angle Imaging SpectroRadiometer (AirMISR). Many of these instruments can be carried on NASA's ER-2 aircraft.

The IPO developed the NPOESS Airborne SounderTestbed (NAST) suite of aircraft sensors and similar sensors including NAST-I, NAST-M and S-HIS which provide NPP-like sounding radiometric observations. These instruments have flown on the Proteus aircraft since 2000 and with instruments such as MIR, MAS, CLS, FIRSC, and Intera on the ER-2 aircraft since 1997.

MAS, NAST-I, NAST-M, S-HIS and AVIRIS will play a key role in NPP products validation. MAS is a fifty channel visible, near-infrared, and thermal infrared imaging spectrometer with 50 m resolution at nadir (King et al. 1996), Scanning HIS, a 2 km resolution at nadir interferometer sounder, NAST-I, a 2.6 km resolution interferometer covering 3.5 to 16 microns with a spectral resolution greater than 2000, NAST-M, a 16 channel microwave radiometer sensitive to 50-60 and 113 -119 GHz radiation from 2.5 km resolution footprints, AVIRIS, a 224 band imaging spectrometer from 0.4-2.5 µm with 20 m resolution at nadir (Vane et al. 1993). All spatial resolutions cited above are for a NASA ER-2 aircraft altitude of 20 km. The ER-2's cruising altitude of 20 km leads to stable attitude control and minimal above-aircraft atmospheric effects. A Table of aircraft instruments planned for use in NPP calibration/validation is provided below.

Table A-3: Airborne Instruments Planned for NPP Calibration Validation Efforts and Corresponding URLs.

Airborne Instrument	URL
MAS	http://ltpwww.gsfc.nasa.gov/MAS/
NAST-I	http://danspc.larc.nasa.gov/NAST/
NAST-M	http://www-nastm.mit.edu/
S-HIS	http://deluge.ssec.wisc.edu/~shis/
PSR	http://www1.etl.noaa.gov/radiom/psr
APMIR	http://www.pxi.com/praxis_publicpages/APMIR.html
AVIRIS	http://makalu.jpl.nasa.gov/
MASTER	http://masterweb.jpl.nasa.gov/
MQUALS	http://gaea.fcr.arizona.edu/validation/index.htm
AirMISR	http://www-misr.jpl.nasa.gov/mission/air.html

Other Satellite Sensors

A significant part of the NPP Cal/Val effort will involve intercomparison of radiances and products derived from NPP with those from EOS, POES, GOES, METOP, EO-3, ENVISAT programs and other available satellite sensors. Maintenance of long-term data sets and continuity of data quality is a mandate for the EOS-NPP-NPOESS series of sensors. These intercomparisons are necessary both for calibration validation effort and climate studies. This document outlines many of these intercomparisons using NPP validation sites [TBR].

Table A-4: Space-borne Sensors Planned for NPP Cross-validation

Name	URL
MODIS	http://modarch.gsfc.nasa.gov/MODIS/MODIS.html
AIRS/AMSU/HSB	http://www-airs.jpl.nasa.gov
GIFTS	http://danspc.larc.nasa.gov/GIFTS
HIRS/AMSU-A	http://orbit36i.nesdis.noaa.gov/atovs/info/hirs_description.html
AVHRR	http://www.osdpd.noaa.gov/EBB/noaasis.html
GLI	http://adeos2.hq.nasda.go.jp/shosai_gli_e.htm
CERES	http://asd-www.larc.nasa.gov/ceres/ASDceres.html
VEGETATION	http://spot4.cnes.fr/spot4_gb/vegetati.htm
ASTER	http://asterweb.jpl.nasa.gov
Landsat-7	http://landsat.gsfc.nasa.gov
SAGE-II	http://www-sage2.larc.nasa.gov
IASI	http://earth.esa.int/METOP.html
MERIS	http://envisat.estec.esa.nl/index.html
AATSR	http://envisat.estec.esa.nl/index.html

Validation Data

Our validation approach relies heavily on the sources of the data that were used in the algorithm development, which consisted primarily of the MAS, NAST-I, NAST-M. In addition, we plan to make extensive use of the AERONET (Aerosol Robotic Network), a network of ground-based sun photometers established and maintained at Goddard Space Flight Center (Holben et al. 1998) that measures the directly transmitted solar radiation and sky radiance, reporting the data via a satellite communication link from each remotely-located sun photometer to Goddard Space Flight Center from sunrise to sunset, 7 days a week.

We also plan to utilize ground-based microwave radiometer observations to derive column water vapor and liquid water path, especially over the Atmospheric Radiation Measurement (ARM) Clouds And Radiation Testbed (CART) site in Oklahoma. For validations of the retrievals over oceans, the measurements of Cloud Liquid Water (CWV) and Liquid Water Path (LWP) from two tropical islands, Nauru and Manus, can be directly available because the Department of Energy will continue to support these field campaigns. The validation of passive microwave estimation of CWV and LWP is largely dependent on the observations from these oceanic environments from these stations (Weng et al., 1997; Grody et al., 2001). North American Radiosondes, in conjunction with GOES retrievals, will be used to validate atmospheric properties (water vapor, stability). GOES retrievals provide the bridge to compare the NPP retrievals with radiosonde measurements. Well-calibrated radiances are essential for the development of accurate algorithms; the calibration of S-HIS and NAST-I is of such a high quality that it serves as a reference for line-by-line radiative transfer models.

The MAS solar channels are calibrated in the field, using a 30” integrating sphere before and after each ER-2 deployment, as well as a 20” integrating hemisphere shipped to the field deployment site for periodic calibrations during a mission. The MAS infrared channels are calibrated through two onboard blackbody sources that are viewed once every scan, taking into account the spectral emissivity of the blackbodies. Calibration of short-wave infrared and thermal infrared channels will be routinely assessed through calibration intercomparisons with S-HIS and NAST-I flying on the same aircraft. A comprehensive description of both the short-wave and long-wave calibration procedures, signal-to-noise characteristics, and thermal vacuum characterization of the MAS can be found in King et al. (1996).

Aircraft data is important to the NPP calibration and validation both before and after launch. Before launch, it will provide the means to demonstrate expected performance and to establish algorithm approaches that will work in the presence of actual atmospheric cloud conditions. After launch, it will form the basis for system validation.

Product validation for the NPP can be established on the basis of shared costs. While expenses associated with maintaining and fielding aircraft instruments can be significant, the requirements for IPO are compatible with those of ongoing NASA scientific programs, NOAA Calibration and Validation of its operational observing capabilities, NASA plans for EOS validation, and DOE field programs for climate studies. Plans are already in place from these and other organizations to support a substantial number of field programs that can be used to leverage IPO support. More specifically, NASA is conducting missions with these instruments throughout the current decade, including the SAFARI mission in South Africa in 2000, a joint water vapor experiment with the DOE centered around the Atmospheric Radiation Measurement (ARM) site in Oklahoma in 2000, Aerosol Characterization Experiments (ACE) in 2001, and a cirrus study with the Cirrus Regional Study of Tropical Anvils and Layers (CRYSTAL) in 2002 and 2004. NOAA will be conducting calibration validation of the operational polar orbiting infrared and microwave sounders periodically in the 2000s; inter-calibration of the ongoing series of POES and EOS sensors and the associated imaging and sounding products is a high priority for these efforts.

Appendix B: EDR and CDR Performance Requirements

B.1 EDR Requirements

Figure B-1 shows the complete list of NPOESS EDRs to be derived during the NPOESS era. Only EDRs from VIIRS, CrIS and ATMS on NPP are addressed in this document.

★	Atmospheric Vertical Moisture Profile	Downward Longwave Radiance (Sfc)	Precipitable Water
★	Atmospheric Vertical Temperature Profile	Electric Fields	Precipitation Type/Rate
★	Imagery	Electron Density Profile	Pressure (Surface/Profile)
★	Sea Surface Temperature	Fresh Water Ice	Medium Energy Charged Particles
★	Sea Surface Winds	Geomagnetic Field	Sea Ice Age and Ice Edge Motion
★	Soil Moisture	Ice Surface Temperature	Sea Surface Height/Topography
	Aerosol Optical Thickness	In-situ Ion Drift Velocity	Snow Cover/Depth
	Aerosol Particle Size	In-situ Plasma Density	Neutral Winds
	Albedo (Surface)	In-situ Plasma Fluctuations	Solar Irradiance
	Auroral Boundary	In-situ Plasma Temperature	Energetic Ions
	Auroral Imagery	Insolation	Supra-Thermal - Auroral Particles
	Cloud Base Height	Ionospheric Scintillation	Surface Wind Stress
	Cloud Cover/Layers	Land Surface Temperature	Suspended Matter
	Cloud Effective Particle Size	Littoral Sediment Transport	Total Auroral Energy Deposition
	Cloud Ice Water Path	Net Heat Flux	Total Longwave Radiance (TOA)
	Cloud Liquid Water	Net Short Wave Radiance (TOA)	Total Water Content
	Cloud Optical Depth /Transmittance	Neutral Density Profile	Mass Loading / Turbidity
	Cloud Top Height	Vegetation Index	Upper Atmospheric Airglow
	Cloud Top Pressure	Ocean Color/Chlorophyll	Surface Type
	Cloud Top Temperature	Ocean Wave Characteristics	
	Currents (Ocean)	Ozone - Total Column/Profile	

★ •EDRs with Key Performance Parameters

On NPP VIIRS CrIS/ATMS **Not On NPP** CMIS

Figure B-1: EDRs to be Provided by NPOESS Instruments

The following Environmental Data Record (EDR) requirements define the environmental data to be derived from the NPP data stream and delivered to users to meet mission needs. The EDR definitions and requirements are from the NPOESS Integrated Operational Requirements Document [IORD] and the NPOESS Technical Requirements Document [TRD].

Parameter thresholds are cited first and objectives are cited second in the following paragraphs. Note that thresholds and objectives listed refer to the minimum requirement at any point where measurements are sensed, (e.g., a requirement for horizontal resolution of 25 km indicates a need for data at that resolution or better across the entire area where data are being measured, unless specifically indicated at nadir (direct overhead view) or worst case (normally at the edge of satellite field of view) resolution separately). Any requirement giving "nadir resolution" as an attribute presumes that the expansion of the resolution at oblique viewing angles is a natural outcome of observing a sphere from space, and does not presume a specific scanning methodology. In these instances, technology will be driven by the nadir, or highest quality, field of view. Global coverage denotes the observation of all points on the Earth or its atmosphere at least once per given time period (consistent with observational requirements).

Data products are required during any weather conditions; however, EDR requirements apply to clear conditions only unless otherwise specified. Thresholds given for attributes broken into "cloudy" (greater than or equal to five-tenths cloud cover), "clear" (less than five-tenths cloud cover), and "all weather" (all cloud conditions and rainfall rates less than 2 mm hr^{-1} km^{-2} unless otherwise specified in individual EDRs) cases indicate the government's recognition that different technologies shall be employed to provide accurate measurements under these three different atmospheric conditions. Threshold value differences among cloudy, clear, and all weather cases demonstrate how the most stringent of the three is required when obtainable, and will add important information in the ultimate operational application of the data.

All data are required at the uncertainty/refresh/resolution stated, for any Earth location/profile. The performance characteristics for the EDR attributes of Vertical Coverage, Measurement Range, Vertical Reporting Interval and/or Vertical Cell Size, and Measurement Precision and Accuracy shall be within the normal/expected sensing range unless specifically indicated otherwise for each EDR.

B.2 Tables of NPOESS Environmental Data Records (EDRs) Requirements for NPP

1. Imagery

Para. No.		Threshold	Objectives
	a. ***Horizontal Spatial Resolution (HSR)**		
40.2.3.1-2	**Deleted**		
40.2.3.1-3	Deleted		
40.2.3.1-4	**1. Nadir**	**0.4 km**	0.1 km
40.2.3.1-5	2 Worst case	0.8 km	0.1 km
40.2.3.1-6	3. Nighttime Visible, worst case	0.74 km	0.65 km
40.2.3.1-18	4. All Weather	40 km	20 km
40.2.3.1-7	b. Horizontal Reporting Interval	Imagery HSR	Derived (gapless or near gapless coverage)
40.2.3.1 -8	c. Horizontal Coverage	Global	Global
40.2.3.1-9	Deleted		
	d. Measurement Range		
40.2.3.1-10	1. Nighttime visible	4.00E-09 to 3.00E-02 W/(cm^2sr)	Includes threshold range
40.2.3.1-11	2. Other bands	0.645 band 5.0 to 468 W/(m^2 sr μm) 3.7 band 210 K to 353 K 11.45 band 190 K to 340 K	Derived
40.2.3.1-12	e. Measurement Uncertainty	Derived	Derived
	f. Mapping Uncertainty		
40.2.3.1-13	1. At nadir	0.4 km	0.4 km
40.2.3.1-14	2. Worst case	1.5 km	0.5 km
40.2.3.1-19	3. All Weather	3 km	
40.2.3.1-15	**g. *Maximum Local Average Revisit Time**	**4 hrs**	(TBD)
40.2.3.1-16	**h. *Maximum Local Refresh**	**6 hrs**	(TBD)

40.2.3.1-17	**i. *Fraction of Revisit Times Less Than a Specified Value**	**At any location at least 75 % of the revisit times will be 4 hours or less**	(TBD)
40.2.3.1-20	j. Latency (S)	90 minutes	15 minutes

2. Atmospheric Vertical Moisture Profile

Units: **g**/kg

Para. No.		Thresholds	Objectives
40.2.1-1	a. Horizontal Cell Size	14 km @ nadir	2 km @ nadir
40.2.1-2	b. Horizontal Reporting Interval	1 to 9 per FOR	2 km
40.2.1-3	c. Vertical Cell Size	2 km	2 km
	d. Vertical Reporting Interval		
40.2.1-4	1. Surface to 850 mb	20 mb	5 mb
40.2.1-5	2. 850 mb to 100 mb	50 mb	15 mb
40.2.1-6	e. Horizontal Coverage	Global	Global
40.2.1-7	f. Vertical Coverage	Surface to 100 mb	Surface to 100 mb
40.2.1-8	g. Measurement Range	0-30 g/kg	0 - 30 g/kg
	h. *Measurement Uncertainty (expressed as a percent of average mixing ratio in 2 km layers)		
	Clear		
40.2.1-9	**1. *Surface to 600 mb**	15%	10%
40.2.1-10	2. 600 mb to 300 mb	14%	10%
40.2.1-11	3. 300 mb to 100 mb	12%	10%
	Cloudy		
40.2.1-12	**4. *Surface to 600 mb**	16%	10%
40.2.1-13	5. 600 mb to 300 mb	18%	10%
40.2.1-14	6. 300 mb to 100 mb	17%	10%
40.2.1-15	i. Mapping Uncertainty	5 km	1 km
40.2.1-16	j. Maximum Local Average Revisit Time	8 hrs	3 hrs
40.2.1-17	k. Deleted.		
40.2.1-18	l. Latency (S)	156 min	15 minutes
40.2.1-19	m. Long-term Stability (C) (CrIS/ATMS)	2%	1%

3. *Atmospheric Vertical Temperature Profile*

Units: K

Para. No.		Thresholds	Objectives
	a. Horizontal Cell Size		
40.2.2-1	1. Clear, nadir	14 km Surface to 0.5 mb 200 km 0.5 to 0.01mb	1 km
40.2.2-2	2. Clear, worst case	50 km	(TBD)
40.2.2-3	3. Cloudy, nadir	40 km	1 km
40.2.2-4	4. Cloudy, worst case	200km	(TBD)
40.2.2-5	b. Horizontal Reporting Interval	One to nine per FOR	(TBD)
	c. Vertical Cell Size		
	Clear		
40.2.2-6	1. Surface to 300 mb	1 km	(TBD)
40.2.2-7	2. 300 mb to 30 mb	3 km	(TBD)
40.2.2-8	3. 30 mb to 1 mb	5 km	(TBD)
40.2.2-9	4. 1 mb to 0.5 mb	5 km	(TBD)
40.2.2-40	5. 0.5 to 0.01 mb		(TBD)
	Cloudy		
40.2.2-10	6. Surface to 700 mb	1 km	(TBD)
40.2.2-11	7. 700 mb to 300 mb	1 km	(TBD)
40.2.2-12	8. 300 mb to 30 mb	3 km	(TBD)
40.2.2-13	9. 30 mb to 1 mb	5 km	(TBD)
40.2.2-14	10. 1 mb to 0.5 mb	5 km	(TBD)
40.2.2-41	11. 0.5 to 0.01 mb	5 km	(TBD)
	d. Vertical Reporting Interval		
40.2.2-15	1. Surface to 850 mb	20 mb	10 mb
40.2.2-16	2. 850 mb to 300 mb	50 mb	10 mb
40.2.2-17	3. 300 mb to 100 mb	25 mb	15 mb
40.2.2-18	4. 100 mb to 10 mb	20 mb	10 mb
40.2.2-19	5. 10 mb to 1 mb	2 mb	1 mb
40.2.2-20	6. 1 mb to 0.1 mb	0.2 mb [1 mb to .5 mb]	0.1 mb
40.2.2-21	7. 0.1 mb to 0.01 mb	0.02 mb	0.01 mb
40.2.2-22	e. Horizontal Coverage	Global	Global
40.2.2-23	f. Vertical Coverage	Surface to 0.01 mb	Surface to 0.01 mb
40.2.2-24	g. Measurement Range	180-335K [EARTH SCENE] 180-310K [BLACK BODY]	162-335 K (TBR)
40.2.2-25	Not Used		
	h. ***Measurement Uncertainty		
	Clear		
40.2.2-26	**1. *Surface to 300 mb**	0.9 K/1 km layer	0.5 K/1 km
40.2.2-27	2. 300 mb to 30 mb	0.98 K/3 km layers	0.5 K/1 km
40.2.2-28	3. 30 mb to 1 mb	1.45 K/5 km layers	0.5 K/1 km
40.2.2-29	4. 1 mb to 0.3 mb**	3.5 K /5 km layers	0.5 K/1 km
40.2.2-41	5. 0.3 to 0.001 mb	6.5 K/5 KM LAYER	
	Cloudy		
40.2.2-30	**6. *Surface to 700 mb**	2.0 K/ 1 km layer	0.5 K/1 km
40.2.2-31	7. 700 mb to 300 mb	1.4 K/ 1 km layer	0.5 K/1 km
40.2.2-32	8. 300 mb to 30 mb	1.3 K/ 1 km layer	0.5 K/1 km
40.2.2-33	9. 30 mb to 1 mb	1.45 K/ 1 km layer	0.5 K/1 km
40.2.2-34	10. 1 mb to 0.0.5 mb	3.5 K /1 km layer	0.5 K/1 km
40.2.2-40	11. 0.5 to 0.01 mb	6.5 K/ 5 km layer	
40.2.2-35	i. Mapping Uncertainty	5 km	1 km
40.2.2-36	j. Maximum Local Average Revisit Time	6 hrs (TBR)	3 hrs
40.2.2-37	k. Deleted.		
40.2.2-38	l. Latency (S)	156 min	15 minutes
40.2.2-39	m. Long Term Stability (C) (CrIS/ATMS)	Trop Mean 0.05 K Strat Mean 0.1 K	TROP 0.03 K Strat 0.05 K

4. *Pressure (Surface/Profile)*

Units: mb

Para. No.		Thresholds	Objectives
40.3.5-1	a. Horizontal Cell Size	25 km,	5 km
40.3.5-2	b. Horizontal Reporting Interval	25 km	5 km
40.3.5-3	c. Vertical Cell Size	0 km	0 km
	d. Vertical Reporting Interval		
40.3.5-4	1. [0 – 2 km]	1 km	0.25 km
40.3.5-5	2. [2 – 5 km]	1 km	0.5 km
40.3.5-6	3. [> 5 km]	1 km	1 km
40.3.5-7	e. Horizontal Coverage	Global	Global
40.3.5-8	f. Vertical Coverage	0-30 km	0 – 30 km
40.3.5-9	g. Measurement Range	10-1050 mb	10 – 1050 mb
	h. Measurement accuracy		
40.3.5-10	1. [0 – 2 km]	3%	
40.3.5-11	2. [2 – 10 KM]	3 %	0.5%
40.3.5-12	3. [10 – 30 km]	5 % [10-30 km]	0.5 %
40.3.5-13	i. Measurement Precision	3 mb	2 mb
40.3.5-14	j. Mapping Uncertainty	3 km	1 km
40.3.5-15	k. Maximum Local Average Revisit Time (S)	8 hrs	1 hr
40.3.5-16	l. Deleted.		
40.3.5-17	m. Latency (S)	156 minutes	15 minutes

5. *Precipitable Water*

Units: mm of condensed vapor

Para. No.		Threshold	Objectives
40.3.3-1	a. Horizontal Cell Size	25 km	1 km
40.3.3-2	b. Horizontal Reporting Interval	25 km	HCS
40.3.3-3	c. Horizontal Coverage	Global	Global
40.3.3-4	d. Measurement Range	0 - 75 mm	0 - 100 mm
40.3.3-5	e. Measurement Accuracy	Land or Ice Greater of 8% or 2 mm Oceqan, Ice-free 1mm	1 mm or 4%
40.3.3-6	f. Measurement Precision	Land or Ice Greater of 5% or 1mm Ocean,Ice-free 1 mm	1 mm
40.3.3-7	g. Mapping Uncertainty	3 km	0.1 km
40.3.3-8	h. Maximum Local Average Revisit Time (S)	8 hrs	3 hrs
40.3.3-9	i. Deleted.		
40.3.3-10	j. Long Term Stability (C)	Greater of 1.0 mm or 10%	Greater of 0.1 mm or 1%
40.3.3-11	k. Latency (S)	90 minutes	15 minutes

6. *Suspended Matter*

Concentration: $\mu g/m^3$

Para. No.		Threshold	Objectives
40.3.1.3-1	a. Horizontal Cell Size	1.6 km	1 km
40.3.1.3-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.3.1.3-3	c. Vertical Cell Size	Total Column	0.2 km
40.3.1.3-4	d. Vertical Reporting Interval	N/A	Vertical Cell Size
40.3.1.3-5	e. Horizontal Coverage	Global	Global
40.3.1.3-6	f. Vertical Coverage	0-30 km	(TBD)
	g. Measurement Range		
40.3.1.3-14	1. Detection	Flag cells where atmosphere	Flag atmospheric layers

		contains suspended matter	containing suspended matter
40.3.1.3-7	2. Type	Dust, sand, volcanic ash, sea salt, smoke, SO_2	Dust, sand, volcanic ash, sea salt, smoke, SO_2, radioactive material, other
40.3.1.3-8	3. Concentration	0 - 1000 μg/m^3 for smoke	0 - 100 μg/m^3 for smoke, other types (TBD)
40.3.1.3-9	h. Probability of Correct Typing	Suspended matter 90% Dust/sand 85% Smoke 85% Volcanic Ash 85% Sea Salt 85%	(TBD) for classes
40.3.1.3-10	i. Measurement Uncertainty (concentration)	Smoke 50%	(TBD)
40.3.1.3-11	j. Mapping Uncertainty	1.5 km	0.1 km
40.3.1.3-12	k. Maximum Local Average Revisit Time (S)	12 hrs	3 hrs
40.3.1.3-13	l. Deleted.		
40.3.1.3-15	m. Latency (S)	90 minutes	15 minutes

7. *Aerosol Optical Thickness*

Units: Dimensionless

Para. No.		Threshold	Objectives
40.3.1.1-1	a. Horizontal Cell Size	1.6 km over ocean; 9.6 km over land	1 km
40.3.1.1-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.3.1.1-3	c. Vertical Cell Size	Total Column	50 km
40.3.1.1-4	1. [0 – 2 km]	N/A	0.25 km
40.3.1.1-5	2. [2 – 5 km]	N/A	0.5 km
40.3.1.1-6	3. [> 5 km]	N/A	1 km
40.3.1.1-7	d. Vertical Reporting Interval	Vertical cell size	Vertical cell size
40.3.1.1-8	e. Horizontal Coverage	Global	Global
40.3.1.1-9	f. Vertical Coverage	0 – 50 km	0 – 50 km
	g. Measurement Range		
40.3.1.1-10	1. Operational	0.0 to 2.0 units of τ	0-10
40.3.1.1-18	2. Climate	0.0 to 5.0 units of τ	0-10
	h. Measurement Accuracy		
40.3.1.1-11	1. Operational, Over Ocean	τ <0.5 -- 0.02 $\tau \geq 0.5$ -- 0.07τ - 0.015	0.01
40.3.1.1-19	2. Climate, Over Ocean	Greater of 0.02 or 7%	Greater of .01 or 5%
40.3.1.1-12	3. Operational, Over Land	τ <1 -- 0.1 $\tau \geq 1$ -- 0.15	0.1
40.3.1.1-20	4. Climate, Over Land	GREATER OF 0.04 OR 10%	Greater of 0.03 or 7%
	i. Measurement Precision		
40.3.1.1-13	1. Operational	Over ocean $\tau \leq 0.6$ -- 0.02 τ >0.6 --0.03 Over land – 0.1	0.01
40.3.1.1-21	2. Climate, Over Ocean	0.01	0.005
40.3.1.1-22	3. Climate, Over Land	0.03	0.02
40.3.1.1-14	j. Long Term Stability	0.01	0.003
40.3.1.1-15	k. Mapping Uncertainty	1.5 km	1 km
	l. Maximum Local Average Revisit Time		
40.3.1.1-16	1. Operational (S)	6 hrs	4 hrs
40.3.1.1-23	2. Climate	N/A	N/A
40.3.1.1-17	m. Deleted.		
40.3.1.1-24	n. Measurement Uncertainty, Operational, over land	τ<0.45 0.05+0.2τ 0.45 <$\tau \leq 1$ 0.14 τ>1 0.18	

8. Aerosol Particle Size

Units: Ångström Wavelength Exponent: Dimensionless. Effective Radius: μm

Para. No.		Threshold	Objectives (Pertaining to effective radius)
40.3.1.2-1	a. Horizontal Cell Size	1.6 km over ocean 9.6 km over land	1 km
40.3.1.2-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.3.1.2-3	c. Vertical Cell Size	Total column	50 km
40.3.1.2-4	1. [0 - 2 km]	N/A	0.25 km
40.3.1.2-5	2. [2 - 5 km]	N/A	0.5 km
40.3.1.2-6	3. [> 5 km]	N/A	1 km
40.3.1.2-7	d. Vertical Reporting Interval	N/A	Vertical cell size
40.3.1.2-8	e. Horizontal Coverage	Global	Global
40.3.1.2-9	f. Vertical Coverage	0 – 30 km	0 - 50 km
	g. Measurement Range		
40.3.1.2-10	1. Operational	-1 to +3 units of α	0.05 to 5 μm
40.3.1.2-17	2. Climate	0 to 5 μm or 10% for r_e 0 to 3 for ν_e	0 to 10 μm or 10% for re 0 to 5 for (e
	h. Measurement Accuracy		
40.3.1.2-11	1. Operational	Ocean _<0.04 -- 0.3 Ocean _>0.04 – 0.1 Land 0.6	10 %
40.3.1.2-19	2. Climate	Greater of 0.1(m or 10% for re Greater of 0.3 or 50% for (e (	GREATER OF 0.05 (M OR 5% FOR RE Greater of 0.2 or 30% for (e
	i. Measurement Precision		
40.3.1.2-12	1. Operational	Ocean _<0.04 -- 0.3 Ocean _>0.04 – 0.1 Land 0.6	10%
40.3.1.2-18	2. Climate	Greater of 0.05(m or 10% for re Greater of 0.1 or 40% for (e (	GREATER OF 0.05 (M OR 5% FOR RE GREATER OF 0.1 OR 20% FOR (E
40.3.1.2-13	j. Long Term Stability (C)	Greater of 0.05_m or 10% for re Greater of 0.2 or 40 % for (e (	GREATER OF 0.05 (M OR 5% FOR RE Greater of 0.1 or 20 % for (e
40.3.1.2-14	k. Mapping Uncertainty	1.5 km	1 km
	l. Maximum Local Average Revisit Time (S)		
40.3.1.2-15	1. Operational	6 hrs	4 hrs
40.3.1.2-20	2. Climate	N/A	N/A
40.3.1.2-16	m. Deleted.		

9. Cloud Base Height

Units: km

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.4.1-1	1. Moderate	10 km	1.0 km
40.4.1-10	2. Fine, nadir	6 km	1.0 km
40.4.1-2	b. Horizontal Reporting Interval	HCS	HCS
40.4.1-3	c. Horizontal Coverage	Global	Global
	d. Vertical Cell Size	N/A	N/A
40.4.1-4	e. Vertical Reporting Interval	Base of highest cloud and lowest cloud	Base of all distinct cloud layers
40.4.1-5	f. Measurement Range	0 – 20 km	0 – 30 km
40.4.1-6	g. Measurement Uncertainty	2 km	0.25 km
40.4.1-7	h. Mapping Uncertainty	1.5 km	1 km
40.4.1-8	i. Maximum Local Average Revisit Time (S)	6 hrs	4 hrs
40.4.1-9	j. Deleted.		
40.4.1-11	k. Long Term Stability (C)	2.0 km	0.1 km
40.4.1-12	l. Latency (S)	90 minutes	15 minutes

10. Cloud Cover/Layers

Units: Dimensionless

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.4.2-1	1. Moderate	25 km	1 km
40.4.2-12	2. Fine, nadir	6 km	1 km
40.4.2-2	b. Horizontal Reporting Interval	HCS	(TBD)
	c. Vertical Cell Size	N/A	N/A
40.4.2-3	d. Vertical Reporting Interval	4 layers	0.1 km
40.4.2-4	e. Horizontal Coverage	Global	Global
40.4.2-5	f. Vertical Coverage	0 - 20 km	0 - 30 km
40.4.2-6	g. Measurement Range	0 - 1.0 HCS Area	0 - 1.0
40.4.2-7	h. Measurement Accuracy	0.07 HCS area (nadir) 0.1 HCS area (EOS)	0.05
40.4.2-8	i. Measurement Precision	0.07 HCS area (nadir) 0.15 HCS area (EOS)	0.025
40.4.2-9	j. Mapping Uncertainty	1.5 km	1 km
40.4.2-10	k. Max Local Average Revisit Time (S)	6 hrs	4 hrs
40.4.2-11	l. Deleted.		
40.4.2-13	m. Latency (S)	90 minutes	15 minutes
40.4.2-14	n. Binary Map HCS	Pixel Size	
40.4.2-15	o. Binary Map HRI	HCS	
40.4.2-16	p. Binary Map Measurement Range	Cloudy/not cloudy	
40.4.2-17	q. Binary Map Probability of Correct typing	Day, Ocean, OD<0.5 92% Day, Ocean, OD>0.5 99% Day, Land, OD<1 85% Day, Land OD>1 93% Night, Ocean OD<0.5 90% Night, Ocean, OD>0.5 96% Night, Land, OD<1 85% Night, Land, OD>1 90%	

11. Cloud Effective Particle Size

Units: (m

Para. No.		Threshold	Objectives
40.4.3-1	a. Horizontal Cell Size	25 km (Moderate, EOS) 5 km (Fine, nadir)	10 km
40.4.3-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.4.3-3	c. Vertical Cell Size	Vertical Reporting Interval	Vertical Reporting Interval
40.4.3-4	d. Vertical Reporting Interval	Up to 4 layers	0.3 km
40.4.3-5	e. Horizontal Coverage	Global	Global
40.4.3-6	f. Vertical Coverage	0 - 20 km	0 - 30 km
40.4.3-7	g. Measurement Range	0-50 _m	(TBD)
40.4.3-8	h. Measurement Accuracy	5.5_m (Day, water, OD<1) 8_m (Day, ice, OD<1) 2_m (Day, water, OD>1) 3.5_m (Day, ice, OD>1) 4_m (Night)	Greater of 5% or 2 (m
40.4.3-9	i. Measurement Precision	1_m (Day, water) 1.5_m (Day, ice,) 2_m (Night)	2%
40.4.3-10	j. Long Term Stability	2%	1%
40.4.3-11	k. Mapping Uncertainty	1.5 km	1 km
40.4.3-12	l. Maximum Local Average Revisit Time (S)	6hrs	3 hrs
40.4.3-13	m. Deleted.		
40.4.3-14	n. Latency (S)	90 minutes	15 minutes
40.4.3-15	o. Fine Measurement Uncertainty	5.5_m (Day, water, OD<1) 12_m (Day, ice, OD<1) 2.5 µm (Day, water, OD>1) 4µm (Day, ice, OD>1) 4µm (Night)	

12. Cloud Optical Thickness

Units: Dimensionless

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.4.6-1	1. Moderate	25 km	10 km
40.4.6-11	2. Fine , nadir	5 km	1 km
40.4.6-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.4.6-3	c. Horizontal Coverage	Global	Global
40.4.6-4	d. Measurement Range	0.1 to 64 (τ units) Day, water 0.1 to 10 (τ units) Day, ice 0.5 to 10 (τ units) Night, ice	(TBD)
40.4.6-5	e. Measurement Accuracy	0.28 (τ units) Day, water, OD≤1 0.08 (τ units) Day, ice, OD≤1 0.16 (τ units) Night, ice, OD≤1 10% Day, water, OD>1 5% Day, ice, OD>1 10% Night, Ice, OD>1	5 %
40.4.6-6	f. Measurement Precision	0.1 (τ units) Day, water, OD≤1 0.023 (τ units) Day, ice, OD≤1 0.025 (τ units) Night, ice, OD≤1 4 % Day, water, OD>1 3 % Day, ice OD>1 5 % Night, ice OD>1	Greater of 2 % or (TBD)
40.4.6-7	g. Long Term Stability	2 %	1 %
40.4.6-8	h. Mapping Uncertainty	1.5 km	1 km
40.4.6-9	i. Max Local Average Revisit Time (S)	8 hrs	3 hrs
40.4.6-10	j. Deleted.		
40.4.6-12	k. Latency (S)	90 minutes	15 minutes
40.4.6-13	l. Fine Measurement Uncertainty	0.3 (τ units) Day, water, OD≤1 0.1 (τ units) Day, ice, OD≤1 0.16 (τ units) Night, ice, OD≤1 10% Day, water, OD>1 10% Day, ice, OD>1 10% Night, Ice, OD>1	

13. Cloud Top Height

Units: km

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.4.7-1	1. Moderate	25 km	1 km
40.4.7-13	2. Fine, nadir	5 km	1 km
40.4.7-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.4.7-3	c. Horizontal Coverage	Global	Global
	d. Vertical Cell Size	N/A	N/A
40.4.7-4	e. Vertical Reporting Interval	Up to 4 layers	Top of all distinct cloud layers
40.4.7-5	f. Measurement Range	0-20 km	(TBD)
	g. Measurement Accuracy		
40.4.7-6	1. Cloud layer optical thickness > 0.1 (TBR)	0.5 km Day, water, OT>1 1 KM NIGHT, WATER OT>1 1 km Ice OT>1	0.3 km

40.4.7-7	2. Cloud layer optical thickness ≤ 0.1 (TBR)	2 km OT ≤ 1	0.3 km
40.4.7-8	h. Measurement Precision	0.3 km	0.15 km
40.4.7-9	i. Long Term Stability	0.2 km	0.1 km
40.4.7-10	j. Mapping Uncertainty	1.5 km	1 km
40.4.7-11	k. Maximum Local Average Revisit Time (S)	6 hrs	4 hrs
40.4.7-12	l. Deleted.		
40.4.7-14	m. Latency (S)	90 minutes	15 minutes
40.4.7-15	n. Fine, Measurement Uncertainty	0.5 km Day, water, OT>1 1 KM NIGHT, WATER OT>1 2 KM DAY, NIGHT, WATER 1 km Ice	

14. Cloud Top Pressure

Units: mb

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.4.8-1	1. Moderate	12.5 km	1 km
40.4.8-17	2. Fine, nadir	5 km	1 km
40.4.8-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.4.8-3	c. Horizontal Coverage	Global	Global
40.4.8-4	d. Measurement Range	50 to 1050 mb	(TBD)
	e. Measurement Accuracy		
40.4.8-5	1. [Surface - 3 km]	100 mb OT≤1, day/night, water 40 mb OT> 1 day, water 70 MB OT>1 NIGHT, WATER	30 mb
40.4.8-6	2. [3 - 7 km]	65 mb OT ≤ 1 40 mb OT> 1	22 mb
40.4.8-7	3. [> 7 km]	30 mb	15 mb
	f. Measurement Precision		
40.4.8-8	1. [Surface - 3 km]	25 mb	10 mb
40.4.8-9	2. [3 - 7 km]	20 mb	7 mb
40.4.8-10	3. [> 7 km]	13 mb	5 mb
	g. Long Term Stability (TBR)		
40.4.8-11	1. [Surface - 3 km]	10 mb	3 mb
40.4.8-12	2. [3 - 7 km]	7 mb	2 mb
40.4.8-13	3. [> 7 km]	5 mb	1 mb
40.4.8-14	h. Mapping Uncertainty	1.5 KM	1 km
40.4.8-15	i. Maximum Local Average Revisit Time (S)	8 hrs	3 hrs
40.4.8-16	j. Deleted.		
40.4.8-18	k. Latency (S)	90 minutes	15 MINUTES
	l. Fine Measurement Uncertainty		
40.4.8-19	1. [Surface to 3 km]	130 mb OT≤1, day, water 100 mb OT<1 night, water 40 mb OT> 1 day, water 80 mb OT>1 night, water	
40.4.8-20	2. [3 – 7 km]	70 mb OT ≤ 1 45 mb OT > 1	
40.4.8-21	3. [> 7 KM]	30 mb	

15. Cloud Top Temperature

Units: K

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.4.9-1	1. Moderate	25 km	1 km
40.4.9-12	2. Fine, nadir	5 km	1 km
40.4.9-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.4.9-3	c. Horizontal Coverage	Global	Global
40.4.9-4	d. Measurement Range	175 to 310 K	(TBD)
	e. Measurement Accuracy		
40.4.9-5	1. Cloud layer optical thickness > 0.1 (TBR)	2 K OT>1, Water cloud, Day 3 K OT>1, Water cloud, Night 3 K OT>1, Ice Cloud	1.5 K
40.4.9-6	2. Cloud layer optical thickness ≤ 0.1 (TBR)	6 K OT < 1	(TBD)
40.4.9-7	f. Measurement Precision	1.5 K	0.5 K
40.4.9-8	g. Long Term Stability	1 K	0.1 K
40.4.9-9	h. Mapping Uncertainty	1.5 km	1 km
40.4.9-10	i. Maximum Local Average Revisit Time (S)	6 hrs	6 hrs
40.4.9-11	j. Deleted.		
40.4.9-13	k. Latency (S)	90 minutes	15 minutes
40.4.9-14	l. Fine Measurement Uncertainty	3 K Water 5 K Ice	

16. Surface Albedo

Units: Dimensionless

Para. No.		Threshold	Objectives
40.5.2-1	a. Horizontal Cell Size	1.6 km (Mod, EOS) 0.75 km (Fine, nadir)	0.5 km
40.5.2-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.5.2-3	c. Horizontal Coverage	Global	Global
40.5.2-4	d. Measurement Range	0 - 1.0 units of albedo	0 - 1.0
40.5.2-5	e. Measurement Accuracy	0.025 units of albedo	0.0125
40.5.2-6	f. Measurement Precision	0.02 units of albedo	0.01
40.5.2-7	g. Long Term Stability	0.01 units of albedo	0.01
40.5.2-8	h. Mapping Uncertainty	1.5 km	1.0 km
40.5.2-9	i. Max Local Average Revisit Time (S)	24 hrs	4 hrs
40.5.2-10	j. Deleted.		
40.5.2-11	k. Latency (S)	150 minutes	60 minutes
40.5.2-12	l. Fine Measurement Uncertainty	0.03 units of albedo	

17. Fire Area and Temperature

Units: Degrees latitude and longitude for geolocation, K for sub-pixel average temperature, m^2 for active fire area.

Para. No.		Thresholds	Objectives
	a. Horizontal Cell Size		
40.6.4.1-1	1. At nadir	0.75 km	0.5 km
40.6.4.1-2	2. Worst case	1.6 km	0.5 km
40.6.4.1-3	b. Horizontal Reporting Interval	HCS	(TBD)
40.6.4.1-4	c. Horizontal Coverage	Land	Land
	d. Measurement Range:		
40.6.4.1-5	1. Sub-pixel average temperature of active fire	800 K – 1200 K	800 K – 1200 K
40.6.4.1-6	2. Sub-pixel area of active fire	from 1000 m^2 to 50 m times ground sample distance in scan direction (TBR)	from $(50\ m)^2$ to 100 m by greater of pixel in-scan and in-track dimensions (TBR).
	E. MEASUREMENT UNCERTAINTY		
40.6.4.1-7	1. Sub-pixel average temperature of active fire	50 K	25 K
40.6.4.1-8	2. Sub-pixel area of active fire	30%	15%
40.6.4.1-9	f. Mapping Uncertainty	0.4km	0.1 km
40.6.4.1-11	g. Maximum Local Average Revisit Time (S)	6 hrs	1 hour
40.6.4.1-12	h. Deleted.		
40.6.4.1-10	i. Deleted		
40.6.4.1-13	j. Latency (S)	90 minutes	15 minutes

18. Land Surface Temperature

Units: K

Para. No.		Threshold	Objectives
40.6.1-1	a. Horizontal Cell Size	0.75 km (nadir) 1.3 km (EOS)	1 km
40.6.1-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.6.1-3	c. Horizontal Coverage	Land	Land
40.6.1-4	d. Measurement Range	213 K - 343 K	183 K - 343 K
40.6.1-5	e. Measurement Accuracy	2.4 K	1 K
40.6.1-6	f. Measurement Precision	0.5 K	0.025 K
40.6.1-7	g. Mapping Uncertainty	1.5 km	1 km
40.6.1-8	h. Max Local Average Revisit Time (S)	6 hrs	3 hrs
40.6.1-9	i. Deleted.		
40.6.1-10	j. Latency (S)	90 minutes	15 minutes
40.6.1-11	k. Measurement Uncertainty, Nadir	2.50 K	

19. Soil Moisture

Units: cm/m (cm of water per meter of soil depth)

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.2.6-1	1. Clear daytime, at nadir	0.75 km	(TBD)
40.2.6-2	2. Clear daytime, worst case	1.6 km	1.6 km
40.2.6-3	3. All weather, at nadir	40 km	2 km
40.2.6-4	4. All weather, worst case	50 km	(TBD)
40.2.6-5	b. Horizontal Reporting Interval	HCS	(TBD)
40.2.6-6	c. Vertical Cell Size	0.1 cm	5 cm
40.2.6-7	d. Vertical Reporting Interval		
40.2.6-8	e. Horizontal Coverage	Land	Land
40.2.6-9	**f. *Vertical Coverage**	**Surface to –0.1 cm** **(SKIN LAYER)**	Surface to -80 cm
40.2.6-10	g. Measurement Range	0 - 100 cm/m	0 - 100 cm/m
	h. Measurement Uncertainty		
40.2.6-11	1. Clear, Bare soil in regions with known soil types (smaller horizontal cell size)	Surface: 5 cm/m up to field capacity, 10 cm/m beyond capacity	Surface: 1% 80 cm column: ±5 %
40.2.6-12	2. Cloudy , Bare soil in regions with known soil types (greater horizontal cell size)	20 cm/m	Surface: 1 cm/m Total 80 cm column: 5 %
40.2.6-13	i. Mapping Uncertainty	1.5 km	1 km
40.2.6-14	j. Maximum Local Average Revisit Time	8 hrs	3 hrs
40.2.6-15	k. Deleted		
40.2.6-16	l. Latency (S)	90 minutes	30 minutes

20. Surface Type

Units:
Type: N/A
Vegetation Cover: per cent

Para. No.		Threshold	Objectives
40.6.4-1	a. Horizontal Cell Size	1 km	0.25 km
40.6.4-2	Deleted		
40.6.4-3	b. Horizontal Reporting Interval	HCS	(TBD)
40.6.4-4	c. Horizontal Coverage	Land	Land
40.6.4-5	Deleted		
	d. Measurement Range		
40.6.4-6	1. Vegetation/surface type	17 Types (Specified above)	17 Types (Specified above)
40.6.4-7	2. Vegetation cover	0 - 100 %	0 - 100 %
40.6.4-8	e. Measurement Accuracy (veg. cover)	2 0%	2 %
40.6.4-9	f. Measurement Precision (veg. cover)	10 %	0.1 %
40.6.4-10	g. Correct Typing Probability (vegetation /surface type)	88 %	98 %
40.6.4-11	h. Mapping Uncertainty	1.5 km	1 km
40.6.4-12	i. Max Local Average Revisit Time (S)	24 hrs	3 hrs
40.6.4-13	j. Deleted.		
40.6.4-14	k. Latency (S)	90 minutes	15 minutes

21. Vegetation Index

Units: Dimensionless

Para. No.		Threshold	Objectives
40.6.2-1	a. Horizontal Cell Size	0.8 km (Mod, EOS) 0.375 km (Fine, nadir)	1 km
40.6.2-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.6.2-3	c. Horizontal Coverage	Land	(TBD)
40.6.2-4	d. Measurement Range	-1 to +1 NDVI units -1 to +1 EVI units	-1 to +1 NDVI units
40.6.2-5	e. Measurement Accuracy	0.016 NDVI units (Mod)	0.03 NDVI units
40.6.2-6	f. Measurement Precision	0.02 NDVI units (Mod)	0.02 NDVI units
40.6.2-7	g. Long Term Stability	0.01 NDVI units	0.04 NDVI units
40.6.2-8	h. Mapping Uncertainty	1.5 km EOS; 0.4 km (nadir)	1 km
40.6.2-9	i. Max Local Average Revisit Time (S)	24 hrs	24 hrs
40.6.2-10	j. Deleted.		
40.6.2-11	k. Measurement Uncertainty for EVI	0.11 units of EVI	
40.6.2-12	l. Long Term Stability (C)	0.04 NDVI units	0.04 NDVI units
40.6.2-13	m. Latency (S)	90 minutes	15 minutes
40.6.2-14	n. Fine Measurement Uncertainty, NDVI	0.020 NDVI units	

22. Sea Surface Temperature

Units: K

Para. No.		Threshold	Objectives
	a. *Horizontal Cell Size		
40.2.4.1	Deleted		
40.2.4.2	Deleted		
40.2.4-3	**1. *Nadir**	**0.8 km**	0.25 km
40.2.4-4	2. Worst case, clear	1.3 km	(TBD)
40.2.4 –18	3. All Weather	40 KM	20 km
40.2.4-24			
40.2.4-5	b. Horizontal Reporting Interval	HCS	(TBD)
40.2.4-23	c. Horizontal Coverage	Oceans	Oceans
40.2.4.6	Deleted		
40.2.4.7	Deleted		
40.2.4-8	d. Measurement Range	271 K – 313 K	271 K – 313 K
	E. MEASUREMENT UNCERTAINTY (SKIN)		
40.2.4 – 9	**1. * Clear**	**0.5 K**	0.1 K
40.2.4 – 20	2. All Weather	0.5 K	0.5 K
40.2.4-25	3. Deleted		
40.2.4-10	f. Measurement Uncertainty (bulk)	0.5 K	0.1 K
	g. Measurement Precision (skin)		
40.2.4 –11	1. Clear	0.27 K	0.1 K
40.2.4-19	2. All Weather	0.5 K	0.1 K
40.2.4-26	3. Deleted		
	h. Mapping Uncertainty		
40.2.4-12	1. Nadir	0.4 km	0.1 km
40.2.4-13	2. Worst case, clear	0.8 km	(TBD)
40.2.4-14	3. All Weather	3 km	3 km
40.2.4-27	4. Deleted		
40.2.4-15	Deleted		
40.2.4-16	i. Maximum Local Average Revisit Time	6 hrs	3 hrs
40.2.4-17	Jj. Measurement Precision (bulk, clear).	0.2 K	0.1 K
40.2.4-21	k. Long Term Stability (C)	0.1 K	0.05 K
40.2.4-22	l. Latency (S)	90 minutes	15 minutes

23. *Ocean Color and Chlorophyll*

Units:
Ocean Color : W m^{-2} μm^{-1} sr^{-1}, Ocean Optical Properties: m^{-1}, Chlorophyll: mg m^{-3}

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.7.6-1	1. Worst case	1.6 km	0.1 km
40.7.6-2	2. Nadir	0.75 km	0.1 km
40.7.6-3	b. Horizontal Reporting Interval	HCS	HCS
40.7.6.7-29	c. Horizontal Coverage	Oceans	Oceans
40.7.6-4	Deleted		
40.7.6-5	Deleted		
	d. Measurement Range		
40.7.6-13	1. Ocean Color	1.0 - 10 W m^{-2} μm^{-1} sr^{-1}	0. 05-10 W m^{-2} μm^{-1} sr^{-1}
	2. Optical Properties		
40.7.6-14	a. Absorption	0.01 – 10 m^{-1}	0.005 – 20 m^{-1}
40.7.6-15	b. Scattering	0.01 – 50 m^{-1}	0.005 – 75 m^{-1}
40.7.6-16	c. Chlorophyll Fluorescence	N/A	Detectable signals in waters with chlorophyll from 0.1 to 50 mg m^{-3} at 1 km resolution.
40.7.6-6	3. Chlorophyll	0.05 – 50 mg/m^3	0.001 - 100 mg/m^3
	e. Measurement Accuracy		
	1. Ocean Color		
40.7.6-17	a. Operational	10 %	5 %
40.7.6-18	b. Deleted.		
	2. Optical Properties		
40.7.6-19	a. Operational	40 %	30 %
40.7.6-20	b. Deleted.		
	3. Chlorophyll		
40.7.6-7	a. Operational	15% Chl <1.0 mg/m^3 30% 1.0 <Chl <10 mg/m^3 50% Chl >10 mg/m^3	20 %
40.7.6-21	b. Deleted.		
	f. Measurement Precision		
	1. Ocean Color		
40.7.6-22	a. Operational	5 %	2 %
40.7.6-23	b. Deleted.		
	2. Optical Properties		
40.7.6-24	a. Operational	20 %	20 %
40.7.6-25	b. Deleted.		
	3. Chlorophyll		
40.7.6-8	a. Operational	20% Chl <1.0 mg/m^3 30% 1.0 <Chl <10 mg/m^3 50% Chl >10 mg/m^3	10 %
	g. Mapping Uncertainty		
40.7.6-9	1. Worst Case	0.8 km (intermediate swath)	0.1 km
40.7.6-10	2. Nadir	0.4 km	0.1 km
40.7.6-11	h. Max Local Average Revisit Time (S)	24 hrs	12 hrs
40.7.6-12	i. Deleted.		
40.7.6-26	j. Long Term Stability (W m^{-2} μm^{-1} sr^{-1}) (C) SEE NOTE 1	Max Chl Absorption 0.5 Min Chl Absorption 0.25 Atmospheric Correction 0.08	Max Chl Absorption 0.25 Min Chl Absorption 0.125 Atmospheric correction 0.04
	k. Latency (S)		
40.7.6-27	1. Operational	180 minutes	60 minutes
40.7.6-28	2. Deleted.		

NOTE 1: STABILITY IS FOR WATER LEAVING RADIANCE AT THE BAND OF MAXIMUM CHLOROPHYLL ABSORPTION (MEASURED AT APPROXIMATELY 445 NM), MIN CHLOROPHYLL ABSORPTION (AT APPROXIMATELY 555 NM), AND ATMOSPHERIC CORRECTION (AT APPROXIMATELY 865 NM).

24. Net Heat Flux

Units: W/m^2

Para. No.		Threshold	Objectives
40.7.5-1	a. Horizontal Cell Size	20 km	5 km
40.7.5-2	b. Horizontal Reporting Interval	HCS	(TBD)
40.7.5-3	c. Horizontal Coverage	Oceans	Global Oceans
40.7.5-4	d. Measurement Range	0 - 2000 W/m^2	0 - 2000 W/m^2
40.7.5-5	e. Measurement Accuracy	10 W/m^2	1 W/m^2
40.7.5-6	f. Measurement Precision	25 W/m^2	1 W/m^2
40.7.5-7	g. Mapping Uncertainty	1.5 km	(TBD)
40.7.5-8	h. Maximum Local Average Revisit Time (S)	6 hrs	3 hrs
40.7.5-9	i. Deleted.		
40.7.5-10	j. Latency (S)	24 hours	6 hours

25. Sea Ice Characterization

Ice age: WMO Nomenclature Class
Ice edge Concentration: Tenths

Para. No.		Threshold	Objectives
40.7.8-1	a. Horizontal Cell Size (Ice Age)		
	Clear	2.4 km	0.1 km
	All Weather	20 km	0.05 km
40.7.8-2	b. Horizontal Reporting Interval	HCS	HCS
40.7.8-3	c. Horizontal Coverage	Oceans	All ice covered regions of the global ocean
	d. Measurement Range		
40.7.8-4	1. Ice Age Classes	New/Young, First Year, Multi-year	Ice free, Nilas, GreyWhite, Grey, White, First Year Medium, First Year thick, Second Year, and Multiyear; Smooth and Deformed Ice
40.7.8-5	2. Ice Concentration	1/10 to 10/10	0/10 to 10/10
40.7.8-6	e. Probability of Correct Typing (Ice Age)	80% (First year from Multi-year) 70% (NEW/YOUNG FROM FIRST YEAR) 70% (New/Young from Multi-year)	90 %
40.7.8-7	f. Measurement Uncertainty (Ice Concentration)	1/10	5 %
40.7.8-8	g. Mapping Uncertainty	1.5 km	0.05 km
40.7.8-9	h. Max Local Average Revisit Time (S)	24 hrs	6 hrs
40.7.8-10	i. Deleted.		
40.7.8-11	j. Long Term Stability (C)	1 % concentration	
40.7.8-12	k. Latency (S)	8 hrs	15 minutes

Fresh Water Ice (Application of Sea Ice Chatracterization)

Para No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.7.8.1-1	Nadir	0.8 km	(TBD)
40.7.8.1-2	Worst Case	3.2 km	4 times 0.65 km (TBR)
40.7.8.1-3	b. Horizontal Reporting Interval	HCS	HCS
40.7.8.1-4	c. Horizontal Coverage	Fresh water	Fresh water
40.7.8.1-5	d. Measurement Range	1/10 to 10/10 concentration	0/10 to 10/10 concentration
	f. Measurement Uncertainty		
40.7.8.1-6	1. Ice edge Boundary	0.4 km Nadir 1.0 km EOS	5 km
40.7.8.1-7	2. Ice concentration	0.10	10%
40.7.8.1-8	g. Mapping Uncertainty	1.5 km	1 km
40.7.8.1-9	h. Max Local Average Revisit Time (S)	24 hrs	6 HRS
40.7.8.1-10	i. Latency (S)	90 minutes	15 minutes

26. Ice Surface Temperature

Above the surface of the ice. This EDR is required under clear conditions only.
Units: K

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.7.3-1	1. Nadir	1.0 km	0.1 km
40.7.3-9	2. Worst case	1.6 km	0.1 km
40.7.3-2	b. Horizontal Reporting Interval	1.0 km	0.1 km
40.7.3-3	c. Horizontal Coverage	Ice-covered land/water	Ice-covered land/water
40.7.3-4	d. Measurement Range	213 K – 275 K	213 K - 293 K (2 m above ice)
40.7.3-5	e. Measurement Uncertainty	0.5 K	(TBD)
40.7.3-6	f. Mapping Uncertainty, nadir	0.4 km	0.1 km
40.7.3-7	g. Maximum Local Average Revisit Time (S)	24 hrs	12 hrs
40.7.3-8	h. Deleted.		
40.7.3-10	i. Latency (S)	90 minutes	15 minutes

27. *Snow Cover and Depth*

Para. No.		Threshold	Objectives
	a. Horizontal Cell Size		
40.6.3-1	1.Clear	0.8 km (nadir) 1.6 km (EOS)	1 km
40.6.3-2	2. All weather and/or nighttime	12.5 km.	1 km
40.6.3-3	b. Horizontal Reporting Interval	HCS	1 km
40.6.3-4	c. Snow Depth Ranges	Snow/No snow	> 8 cm, > 15 cm, > 30 cm, >51 cm, >76 cm
40.6.3-5	d. Horizontal Coverage	Land Snow/No snow	Land & Ice
40.6.3-6	e. Vertical Coverage	Land	0 - 1 m
40.6.3-7	f. Measurement Range	0 – 1 HCS	0 - 1 per snow depth category
	g. Measurement Uncertainty		
40.6.3-8	1.. Clear - daytime	10 % (snow/no snow)	10 % for snow depth
40.6.3-9	2. Cloudy and/or nighttime	20 % (snow/no snow)	10 %
	h. Mapping Uncertainty		
40.6.3-10	1. Clear	1.5 km (EOS)	1 km
40.6.3-11	2. Cloudy	3 km (EOS)	1 km
40.6.3-12	i. Max Local Average Revisit Time (S)	12 hrs	3 hrs
40.6.3-13	j. Deleted.		
40.6.3-14	k. Binary HCS	Clear, day, nadir 0.4 km Clear, day, EOS 0.8 km	
40.6.3-15	l. Sensing Depth (all weather)	0 to 40 cm	1 m
40.6.3-16	m. Long Term Stability (C)	10 %	1% continental
40.6.3-17	n. Latency (S)	90 minutes	15 minutes
40.6.3-18	o. Binary Map- Measurement Range	Snow/No Snow	
40.6.3-19	p. Binary Map- Probability of Correct Typing	95%	

B.3 Climate Data Records (CDRs) Requirements

(To be included after NRA selection)
These are potential CDRs, but the list of CDRs might include all, part and/or other CDRs.

1. Clear Column Radiance (CDR)
To be included

2. Ozone Profile (CDR & EDR)
To be included

3. Precipitation Rate (CDR & EDR)
To be included

4. Trace Gases (CDR & EDR)
To be included

5. Cloud Ice Water Path (CDR & EDR)
To be included

6. Cloud Liquid Water (CDR)
To be included

7. Atmospherically Corrected Reflectance (CDR)
To be included

8. Fire Area and Temperature (CDR & Application)
To be included

9. LAI/FPAR (CDR)
To be included

10. Sea Surface Temperature (CDR & EDR)
To be included

11. Ocean Color (Water Leaving Radiance) (CDR and EDR)
To be included

Appendix C: Verification to NIST Standards

This appendix provides details of the NIST verification plan summarized in Section 4.5. It starts by defining the five types of intercomparison activity in Section C.1. Then Section C.2 gives background information on the existing NIST measurement infrastructure relevant to the verification plan. Additional NIST resources that will be developed for this plan are described in Section C.3."

C.1 Definition of the Types of NPP Intercomparison Activities for NIST Traceability Verification

Type A: BRDF Round-Robin of Diffuser Plates.

This is primarily to verify the bi-directional reflectance distribution function (BRDF) scale used in the calibration of VIIRS. VIIRS will use one or more reflective diffuser plates as diffuse reflectance standards for the solar-reflective bands. To verify the diffuse reflectance scale used by the Raytheon SBRS team for VIIRS, one or more diffuser plates will be measured by NIST, SBRS, and any other participants. In such a round-robin, artifacts are sent around to the different participating laboratories with measurements performed on the artifacts at each laboratory. The EOS-heritage example of this is described in Ref. 1 [see NIST References at the end of this appendix]. The measurement performed at each laboratory is the BRDF of the artifact. The artifact is a sample of the same type of material, such as a Spectralon panel, that serves as the reflectance reference panel on the flight instrument. It is not the flight-panel(s) itself. The protocol for the measurements is developed by NIST after consultation with the participating measurement laboratories. Table C-1 gives an example protocol. Based on experience, the expanded uncertainty (k=2) [see Ref. 18 for uncertainty definitions, k=2 means a 95% confidence level, commonly called 2-sigma_] determined by combining the standard uncertainties from NIST and a typical participating laboratory can be expected to be about 1.4%, and agreement with NIST is generally within 1.5% [1].

Such round-robins usually take a few months to complete, since each laboratory does the measurements at their own facility. The plan for NPP is to perform this round-robin once during the program, near the time that Raytheon SBRS will be calibrating the flight reflectance panel(s). We estimate this to take place in the year 2003.

Table C-1: Example Protocol for NPP BRDF Round-Robin Activity

Parameter	Value
Sample	Spectralon
Wavelengths (nm)	440, 550, 633, 670, 860, 940, 1240
Bandwidth (nm)	10
Incident polar angles (deg)	0, 30, 45, 60
Viewing polar angles (deg)	-60 to 60 in steps of 10
Measurement plane	In-plane and 90 degrees Out-of-plane
Polarization state	Report BRDF for unpolarized light
Sample size	50.8 mm diameter
Sample alignment	Fiducial mark on holder

Type B. Intercomparison of Lamp-Illuminated Integrating Spheres/Plaques and Radiometers.

This is to verify spectral radiance scales used by instrument-providers in the solar-reflective part of the spectrum. Such scales are normally established by the instrument-providers using lamp-illuminated spheres or plaques. It is relevant for the solar-reflective channels of VIIRS, and for instruments used in validation of solar-reflective products such as ocean color. One goal is to compare the spectral radiance of the VIIRS calibration source as used by SBRS to that determined by NIST using NIST-calibrated radiometers. Another goal is to do the equivalent for spheres or plaques used by any NPP validation instruments, such as MAS. Examples of this type of activity from the EOS heritage are described in Refs. 2-4 [see NIST References at the end of this appendix]. Ref. 2 describes an intercomparison performed at the MODIS instrument contractor site, SBRS, in 1996. Ref. 4 describes an intercomparison performed at the MAS aircraft instrument calibration site. In either case, all participants bring their equipment to a common site and spend a few days performing radiance measurements. The participants use one or more standard radiometers or spectroradiometers to make measurements of the spectral radiance of one or more lamp-illuminated integrating spheres or lamp-illuminated diffuser plaques, at a number of wavelengths that overlap flight-instrument channels. For a filter radiometer looking at a source, the comparison approach is to compute the spectral radiance using the radiance spectrum provided by the calibration facility and the relative spectral response functions of the radiometer. This gives a predicted radiometer response. The percent difference between the measured radiometer response and the predicted radiometer response then indicates how well the spectral radiance spectrum of the calibration facility compares to the NIST spectral radiance scale. Based on experience, expected agreement is about 2% in the visible/near-infrared and 4% in the short-wave-infrared [4].

The plan for NPP is to have annual intercomparisons of this type involving MAS and other solar-reflective-band validation instruments. It is anticipated that SBRS would also participate in at least one of these, near the time that its sphere source is used for the VIIRS pre-flight calibration. The annual intercomparisons, starting in the year 2004, should be scheduled near the time of actual MAS flight campaigns to minimize the impact of the drifting of scales.

Type C. Chamber deployment of NIST thermal-IR spectroradiometer to view chamber calibration sources in-situ.

This is to verify the thermal-infrared radiance scales used for pre-flight calibration of CrIS and VIIRS. A prototypical example of this type of activity is described in Refs. 5-6 [see NIST References at the end of this appendix], where the NIST Thermal-infrared Transfer Radiometer (TXR) was used to verify the scale at the calibration chamber at Los Alamos National Laboratory. This has also been performed at the GOES calibration chamber at ITT. The goal of this activity is to make measurements of the thermal-IR radiance that was present at the flight instrument during its pre-flight radiometric calibration. Thus a chamber-compatible, portable radiometer from NIST (the TXR for EOS, the FTXR for NPOESS) is mounted in the vacuum chamber in the location of the flight instrument and views the sources, usually blackbodies, which the flight instrument viewed during radiometric calibration. The comparison approach is similar to that described above for the Type B activity, except that it is common practice in the thermal-IR to convert band-integrated radiance to brightness temperature. Based on experience, expected radiance uncertainties should be around 0.1% to 0.2% at 5 micrometers, which corresponds roughly to a brightness temperature uncertainty of 0.05 K [5, 6]. The strawman protocol is to use the NIST thermal-IR spectroradiometer to make measurements of the radiance of the Earth calibration black body target at 5 to 9 temperature settings that span the temperature range 250 K to 350 K. The space-view target is also viewed, with the goal of verifying the chamber background contribution. This activity usually takes about two weeks of chamber time. As the sources to be viewed are not part of the actual flight instrument themselves, this activity can be performed either right before or right after the NPP VIIRS and CrIS pre-flight chamber calibrations. We are currently planning on this occurring in the year 2004 for both CrIS and VIIRS.

Type D. Thermal-infrared intercomparison of blackbodies and radiometers (at ambient temperature and pressure).

This is to verify the thermal-infrared radiance scales used for validation instruments such as those used on the IPO NAST-I and the thermal-infrared channels of MAS. The participants will use one or more standard radiometers or spectroradiometers to make measurements of the radiance (often converted to brightness temperature) of one or more blackbody sources over the thermal-IR wavelength range. NIST will bring a standard water-bath blackbody and a well-calibrated radiometer (the TXR or eventually the FTXR) to enable NIST radiometric traceability. Other participants (NAST-I, MAS, or others) will bring the blackbody calibration sources that they use to calibrate their validation radiometer instruments and, where possible, their validation radiometer instruments themselves. There will be multiple instruments being compared at a single site in this activity, similar to the Type B activity described above. The NIST radiometer will view the blackbodies, and the validation radiometer instruments will view the NIST blackbody.

In this way the scales can be compared against the NIST radiance scale and their uncertainties verified.

The plan for NPP is to have annual intercomparisons of this type, starting in the year 2004, involving NAST-I, MAS and any other thermal-infrared validation instruments. These intercomparisons will last a few days and should be scheduled near the time of actual NAST-I or MAS flight campaigns to minimize the impact of the drifting of scales.

An example of this type of intercomparison amongst the sea-surface temperature validation community occurred in May 2001 at the University of Miami [7]. The NIST TXR and water bath blackbody participated, and data are currently being analyzed. A predecessor to this was the 1998 intercomparison, also at the University of Miami [8-10].
In the 1998 intercomparison, an M-AERI, a sea-surface temperature radiometer developed by the University of Wisconsin and used for MODIS validation by the University of Miami, viewed a NIST water-bath blackbody. As an example of the expected results, in the spectral range of the M-AERI between 3.3 micrometers and 15 micrometers (excluding regions effected by the air path in the room) the M-AERI agreement with the NIST water bath blackbody was within 0.02 C at 20 C, within 0.03 C at 30 C, and within 0.05 C at 60 C [10]. This was within the combined uncertainties of the M-AERI and NIST water bath blackbody, which was estimated to be about 0.1 C. This type of intercomparison gives confidence that the standards used in the field for validation campaigns in the thermal-IR wavelength range are accurate, and it is worth repeating it occasionally to be sure that these standards have not drifted.

Type E: Intercomparison with Portable Laser-Illuminated Integrating Sphere Source.

This is a newly developed method at NIST for measuring the spectral radiance responsivity of spectroradiometers using a portable, wavelength-tunable laser-illuminated integrating sphere source. The source has a radiance scale directly traceable through a portable irradiance trap detector to the NIST radiometric infrastructure as described below in Section C.3 for the SIRCUS facility. The portable version of this method, known as the "Travelling-SIRCUS," is currently being used to unravel stray-light issues in the spectrographs used in the NOAA MOBY ocean color validation program through a series of three deployments in 2001-2002 to the MOBY site in Hawaii. The MOBY measurements of ocean-leaving radiance are being used to validate MODIS ocean color products, so the correction of MOBY for stray-light is becoming increasingly significant. Using a set of portable dye lasers and a portable Ti-Sapphire laser with an appropriate doubling cavity, the Travelling-SIRCUS currently offers continuous tunability from 360 nm to 980 nm except for a gap at 450 nm to 550 nm. Soon it will be extended by adding a laser that is tunable from 1000 nm to 2500 nm, and the 450 nm to 550 nm gap will be closed in the future with the addition of a new pump laser. For NPP, we propose using the Travelling-SIRCUS to measure the spectral radiance responsivity of the MOBY spectrograph to update stray-light corrections in the MOBY spectrographs prior to use of MOBY for VIIRS ocean-color EDR validation.

C.2 Existing NIST Radiometric Infrastructure

NIST Reflectance Standards

The reflectance-measuring facility at NIST that relates to cal/val of the solar-reflective bands of VIIRS is the Spectral Tri-function Automated Reference Reflectometer (STARR). This facility is used to measure absolute BRDF of diffuse reflecting panels from 250 nm to 2500 nm. The incident and reflected fluxes are measured along with the polar viewing angle and the solid angle of the receiver. The source consists of xenon-arc or quartz-tungsten-halogen lamps, a monochromator, a Glan-Taylor polarizer, and associated optical components. The receiver has a precision aperture, a focussing lens, and Si, Ge, or InAs photodiodes. The STARR goniometer consists of the sample holder and the receiver [20]. The STARR facility has been used to calibrate reflectance standards used throughout the remote sensing community, and it has acted as the central facility in a diffuse reflectance panel round-robin that was performed for EOS [1]. It will act as the central facility in the round-robin planned for NPP Cal/Val.

NIST Radiance Standards

The NIST radiance scale for ultraviolet through infrared wavelengths has been established and maintained by the Optical Technology Division at NIST. As it extends over a wide variety of wavelengths, radiance temperatures, and environmental conditions, there are several facilities within the division at which different parts of the radiance scale are implemented. This sub-section describes how the NIST radiance scale is implemented on the NIST facilities that are relevant for space-based remote sensing applications. It also describes how NIST portable transfer radiometers used for verification of radiance scales throughout the remote sensing community are calibrated at NIST.

The primary standard for radiometric measurements at NIST is the High Accuracy Cryogenic Radiometer (HACR) [22]. This is an electrical substitution radiometer that works at liquid helium temperatures. During the last twenty years, electrical substitution radiometers such as the HACR operated at cryogenic temperatures have become the standard method in most National Measurement Institutes (NMI) for determination of the quantity of optical power in SI units. The radiant power scale maintained by the HACR is disseminated through transfer standards, usually silicon trap detectors. A silicon trap detector is a set of three or more silicon photodiodes in a light trapping arrangement. The responses from the component photodiodes are summed so that the trap detector as a whole has nearly 100% external quantum efficiency. The trap detector responsivity is determined by comparison to the HACR in a series of response measurements of an intensity stabilized, polarized laser beam of about 1 mW power. The responsivities of trap detectors are routinely determined at several laser wavelengths spanning the visible spectrum at an uncertainty of 0.02% uncertainty (k=2) [see Ref. 18 for uncertainty definitions, k=2 means a 95% confidence level, commonly called 2-sigma]. Trap detectors are small, portable, and repeatable. After calibration against the HACR they are taken to a variety of other facilities at NIST and used as reference standards there.

Of particular importance to the method planned for NIST verification of NPOESS radiance scales is the Spectral Irradiance and Radiance Response Calibrations with Uniform Sources (SIRCUS) facility at NIST. This facility is used to measure the spectral responsivity of portable transfer radiometers, such as the ones currently deployed to EOS facilities and those planned for deployment to NPP and NPOESS-related facilities. Laser-illuminated integrating spheres are used as the sources, and trap detectors calibrated against the HACR are used as reference detectors. The integrating sphere is illuminated through a small (few millimeters) input port and provides diffuse radiance to the radiometer under test through a relatively large (up to several centimeters) output port. From ultraviolet wavelengths to near 1 micrometer, the integrating spheres are coated with a white diffuse reflecting material. Beyond 1 micrometer, diffuse-gold-coated integrating spheres are used. The input laser beam is intensity stabilized to near 0.01% or better, and it can be shuttered or chopped as necessary. Laser speckle is removed either by fast scanning of the input beam against the inside of the sphere wall or by fiber-optically coupling the laser to the sphere with a length of the fiber passing through an ultrasonic bath. Using a combination of Ti-Sapphire, dye, and other lasers, in combination with appropriate doublers and quadruplers, continuously tunable CW sphere input powers in the Watt range are available throughout most of the UV, visible, NIR and SWIR. For the thermal IR, the facility has CO_2 and CO lasers to provide discrete-tunable CW powers in the Watt range out to eleven micrometers with some gaps. With such sphere input power, typical power levels at the input aperture of radiometers viewing the sphere can be in the microwatt to milliwatt range if the sphere size is kept to a minimum. A large computer-controlled translation stage is used to provide translations. An electronic ruler is installed to provide source-to-radiometer distance measurements.

The SIRCUS facility is used to provide a known irradiance or radiance so that the responsivity of a portable transfer radiometer under test can be determined. The irradiance at any distance from the output of the sphere can be measured using a reference detector. For the visible spectrum, the reference detector is simply a calibrated silicon trap detector fitted with an aperture of known area. Aperture areas are measured to better than 0.01% using a dedicated facility in the Optical Technology Division at NIST [21]. In the SIRCUS facility, when the radiometer entrance aperture is far enough from the sphere exit aperture that the irradiance falls off as $1/s^2$ (where s is the spacing between the apertures), the sphere exit approximates that of a point source. In this case, irradiance measurements at one radiometer position (i. e., the irradiance trap reference detector) are used to infer the irradiance at another radiometer position (i. e. the portable transfer radiometer under test). In this way the radiometer under test is calibrated for irradiance responsivity against the reference detector, and the aperture spacing s can usually be determined at negligible uncertainty levels. From geometric measurements of s and the sphere exit aperture area, the solid angle subtended by the sphere exit aperture is known. Thus the irradiance measured by the reference detector at any s can be used to determine the radiance of the exit port of the sphere. Finally, when the radiometer under test is positioned close enough to the sphere exit that its entrance pupil is filled, the sphere appears as an extended source of known radiance at a particular wavelength. By scanning the wavelength and comparing reference detector response to the radiometer-under-test response, the system-level radiance responsivity versus wavelength of the transfer radiometer is measured. This method has many advantages over previous methods. In particular, it provides the spectral and radiometric calibration together in a single step, and has a much shorter measurement chain to the HACR. The SIRCUS facility has been used over the past few years to calibrate several radiometers, including NIST transfer radiometers used in cal/val in the NASA EOS program.

While the SIRCUS facility is a permanent installation at NIST, recently (FY2001) a portable version has been developed and named the Travelling-SIRCUS. This consists of set of portable dye lasers, a portable Ti-Sapphire laser with an appropriate doubling cavity, a fiber-optically fed portable integrating sphere, and an irradiance trap detector for determining the radiance output of the sphere during deployments. The Travelling-SIRCUS currently offers continuous tunability from 360 nm to 980 nm except for a gap at 450 nm to 550 nm. Soon it will be extended by adding a laser that is tunable from 1000 nm to 2500 nm, and the 450 nm to 550 nm gap will be closed in the future with the addition of a new pump laser.

For the short-wave and thermal-infrared spectrum, where silicon-trap detectors no longer work, a HACR-traceable, helium-cooled bolometer fitted with a precision aperture is used as the reference detector at the SIRCUS facility.. Note that in the thermal-infrared, the diffuse-gold integrating sphere will itself present a gray body radiance to radiometer. Thus, in addition to the delta-function from the laser, a continuum radiance will exist; the exact spectral shape of which will depend on the spectral emissivity characteristic of the sphere wall coating and the effective temperature of the sphere wall. This unwanted continuum is removed by chopping the input laser and using chopper-synchronous detection on the radiometer response measurements.

The spectral radiance of standard sources such as strip lamps or lamp-illuminated integrating spheres is routinely measured in the NIST Facility for Automated Spectroradiometric Calibrations (FASCAL) [12]. This is the same facility that supplies calibrated FEL irradiance lamps to a wide range of customers, including many in the remote sensing validation community, such as the MAS calibration team, who use the lamps to set up their own radiance scales. The FASCAL facility uses a prism/grating double monochromator-based spectroradiometer to transfer the spectral radiance scale between different sources over the wavelength range 250 nm to 2500 nm. The starting point is the radiance from a gold-point black body at 1337.33 K, as defined on the ITS-90. Its scale is transferred to high-stability vacuum lamp, then to a working standard lamp. The working standard lamp is used to calibrate a variable temperature black body, and this is used to calibrate the source under test. Comparisons of high-temperature sources have indicated that the radiance scale from the gold-point black body is consistent with the radiance scale derived from the HACR to within the combined uncertainties of the measurements, which was roughly +/- 0.5 K [19].

For the thermal-infrared, NIST has a vacuum-compatible cryogenic black body that has large aperture (10 cm diameter) and works over the temperature range 250 K to 350 K [16]. Also, NIST maintains one on-site water bath blackbody that has a large aperture (10 cm diameter) and works over the temperature range 15 C to 90 C [17]. These blackbodies have a radiance scale traceable to the NIST temperature scale through platinum resistance thermometers that measure the temperature near their radiating surfaces. Though common throughout the remote sensing community, NIST experience is that several systematic errors can occur with such black bodies and that they should be checked radiometrically against electrical-substitution based scales to verify uncertainty below 1 K. Work at NIST to establish such consistency of the NIST radiance scale for these NIST black bodies is ongoing, and the goal for consistency is +/- 0.1 K or less.

C.3 NIST Resources to be Developed for NPOESS

While the HACR, SIRCUS, FASCAL, and other facilities for calibration and characterization of portable transfer radiometers and sources in the NIST Optical Technology Division already exist, the actual transfer radiometers and sources themselves need to be built in the years FY02-FY03 preceding the intercomparisons. In many cases these instruments are simply copies of instruments built for other programs. In some cases improved designs are planned. This section details the plans for obtaining, characterizing, and calibrating these instruments.

Portable Lamp-Illuminated Integrating Sphere

This will be a copy of a portable integrating sphere source developed for the NASA EOS program [11]. It will be calibrated for spectral radiance from 400 nm to 2400 nm at the NIST FASCAL facility [12].

Portable VIS/NIR Spectro-radiometer

This instrument will be developed using some existing monochromator parts. It will be a grating spectroradiometer and cover the wavelength range 400 nm to 1100 nm. It will be characterized and calibrated for spectral radiance responsivity over this wavelength range at the NIST SIRCUS facility [14].

Portable SWIR Spectro-radiometer

This will be a copy of the grating spectroradiometer that was developed for the NASA EOS program [13]. The wavelength range is 0.8 micrometers __to 2.5 micrometers. It will be characterized and calibrated for spectral radiance responsivity over this wavelength range at the NIST SIRCUS facility [14].

Portable Thermal-IR FTIR Spectro-radiometer (FTXR)

This will be a cryogenic FTIR interferometer with appropriate field of view-limiting foreoptics and two on-board black bodies to hold the calibration. It will be analogous to the M-AERI, except that it will be vacuum/cryogenic compatible in the same sense as the TXR, a two-channel thermal-infrared transfer radiometer that was developed for the NASA EOS program [15]. The wavelength range will be 2 micrometers to 12 micrometers. It will be characterized and calibrated for spectral radiance responsivity at the NIST SIRCUS facility [14], and it will be tested prior to intercomparison deployments in cryogenic vacuum chamber conditions at the NIST MBIR facility [16]. Since it will be packaged in a sealed vacuum cryostat, it will be compatible both with bench-top deployments for validation field instrument verifications, and with thermal vacuum chamber deployments for vacuum black body radiance scale verifications.

Portable Water Bath Blackbody

This will be a copy of the Water Bath Blackbody described in Ref. 17. This design has been successfully replicated several times for different programs. It was also used once previously in a sea-surface temperature radiometer intercomparison with the M-AERI and other field instruments [8-10].

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C.5 NIST Acronyms

ATMS Advanced Technology Microwave Sounder
BRDF Bi-directional Reflectance Distribution Function
CrIS Crosstrack Infrared Sounder
EDR Environmental Data Record
EDU Engineering Design Unit
EOS Earth Observing System
FASCAL Facility for Automated Spectral Irradiance and Radiance Calibrations
FTIR Fourier Transform Infrared
FTXR FTIR Thermal-infrared Transfer Radiometer
FY Fiscal Year
HACR High Accuracy Cryogenic Radiometer
IR Infrared
ITS-90 International Temperature Scale of 1990
M-AERI Marine-Atmospheric Emitted Radiance Interferometer
MAS MODIS Airborne Simulator
MBIR Medium Background Infrared
MODIS Moderate Resolution Imaging Spectroradiometer
MOBY Marine Optical Buoy
NASA National Aeronautics and Space Administration
NAST-I NPOESS Airborne Sounder Testbed-Interferometer
NAST-M NPOESS Airborne Sounder Testbed-Microwave
NIR Near-infrared
NIST National Institute of Standards and Technology
NMI National Measurements Institute
NPOESS National Polar-orbiting Operational Environmental Satellite System
NPP NPOESS Preparatory Project

SIRCUS Spectral Irradiance and Radiance Responsivity Calibrations with Uniform Sources
STARR Spectral Tri-function Automated Reference Reflectometer
SWIR Short-wave infrared
TBD To Be Determined
VIIRS   Visible/Infrared Imager/Radiometer Suite
Vis Visible

Appendix D: VIIRS Instrument Characterization and Calibration Tests

D.1 VIIRS Characterization

Instrument characterization enables the determination of the quantitative effect of the subsystem level performance on the overall instrument system-level performance. Special care should be taken to decide which characterization test should be performed in the ambient environment or in both ambient and vacuum environments. Sensor Characterization tests include:

D.1.1 Sensor Response Versus Scan Characterization

a) Variation of mirror reflectance as a function of the angle-of-incidence, commonly called Response Versus Scan angle.
b) The variation in reflectance associated with the RVS also coincides with a variation in emittance as a function of angle. Accordingly, the sensor self-emission varies as a function of scan angle. This will be referred to as Emission Versus Scan angle (EVS).

D.1.2 Polarization Characterization

a) Polarization characteristics with scan angle and spectral bands.

D.1.3 Spectral Response

a) Relative Spectral Response (RSR) for each detector/spectral channel combination.
b) Total system spectral response function (best estimate) for all bands.

D.1.4 Calibration Tests for Several Instrument Thermal Configurations

a) Stabilized to isothermal temperatures in foreoptics..
b) Simulated "in-flight" temperature gradients (orbit low in earth shadow, orbit high in daylight).
c) Selected foreoptics components at a high temperature (use clip on heater).

D.1.5 Stray Radiation Characterized as a Function of View Angle

a) Background when viewing blackbody.
b) Background when viewing space.
c) Background when viewing earth target.

D.1.6 Non-linear Detector Response and Repeatability

a) At least ten external target temperatures.
b) Repeated measurements at different times.

D.1.7 Radiance Versus Counts ($R=a+b*C+q(T)*C^2$)

a) For each thermal configuration.
b) For each detector.
c) For each spectral channel.
d) Half of test data will be used to specify algorithm, half to determine calibration algorithm performance.

D.1.8 Band to Band Cross Talk Characterization

D.1.9 Modulation Transfer Function (MTF) Characterization

a) Characterization of the MTF using the Integration and Alignment Collimator (IAC) with the calibration sources (SIS and blackbody).

D.1.10 Alignment and Band to Band Registration

a) Alignment refers to errors in corresponding pixel alignment between bands, and it also refers to the alignment between the VIIRS and the spacecraft platform.
b) The Integration and Alignment Collimator will be used to determine pointing knowledge, within band pixel registration, and Spectral Band Registration (SBR).
c) Interferometrically measured IAC scan and track motions.
d) Selection and testing of misalignment correction software.

D.1.11 Ghosting

a) Characterization of the light backscatter in the instrument's optics, such as lenses and mirrors.

D.1.12 Near Field Response and Point spread Function

a) Near field response characterization in order to verify compliance with the transient response and electronic cross-talk.

D.1.13 Precision, SNR and NEdT

a) Precision is a measure of repeatability of the observations.
b) The SIS will be used to measure the SNR and precision for each reflective band detector.
c) The Blackbody Calibration Source (BCS) and Space View Source (SVS) will be used to measure the NedT's for each detector (i.e., channel) as part of the calibration process.

D.2 VIIRS Calibration Procedures

Calibration is the process of quantitatively defining the instrument/system response to known, controlled signal inputs. It is fundamental for VIIRS instrument, scheduled for the NPP mission, and NPOESS thereafter, to have a robust pre-launch and post-launch characterization and calibration plan, describing in details the steps to effectively understand the sensor components functionality and eliminate the biases and sensor degradation variability.

The characterization process will follow a well-defined protocol and guidelines. These are the result from a long-term experience within NASA and NOAA and from MODIS and AVHRR calibration and characterization teams.
The VIIRS sensor calibration will incorporate onboard calibration, including the Solar Diffuser (SD) and thermal blackbody. The calibration process will also include solar, deep space, and lunar radiometric calibration capability.

The collected spectral radiance and calibration data are transmitted to the ground as Raw Data Records (RDRs). The VIIRS algorithms are applied to the RDRs to produce Sensor Data Records (SDRs) and Environmental Data Records (EDRs).

The actual test plan that will be implemented will be similar to the MODIS plan. The algorithms used for data reduction were verified on MODIS and should be mostly adaptable to VIIRS acceptance testing (Figure D-1).

The data acquired during VIIRS acceptance testing are stored, and specialized reduction algorithms are used to analyze, correct and list final results. The final results are typically in the form of tabulated averaged values with associated standard deviations. Most reduction processes have intermediate files that may be used in a diagnostic mode to determine cause of anomalies.

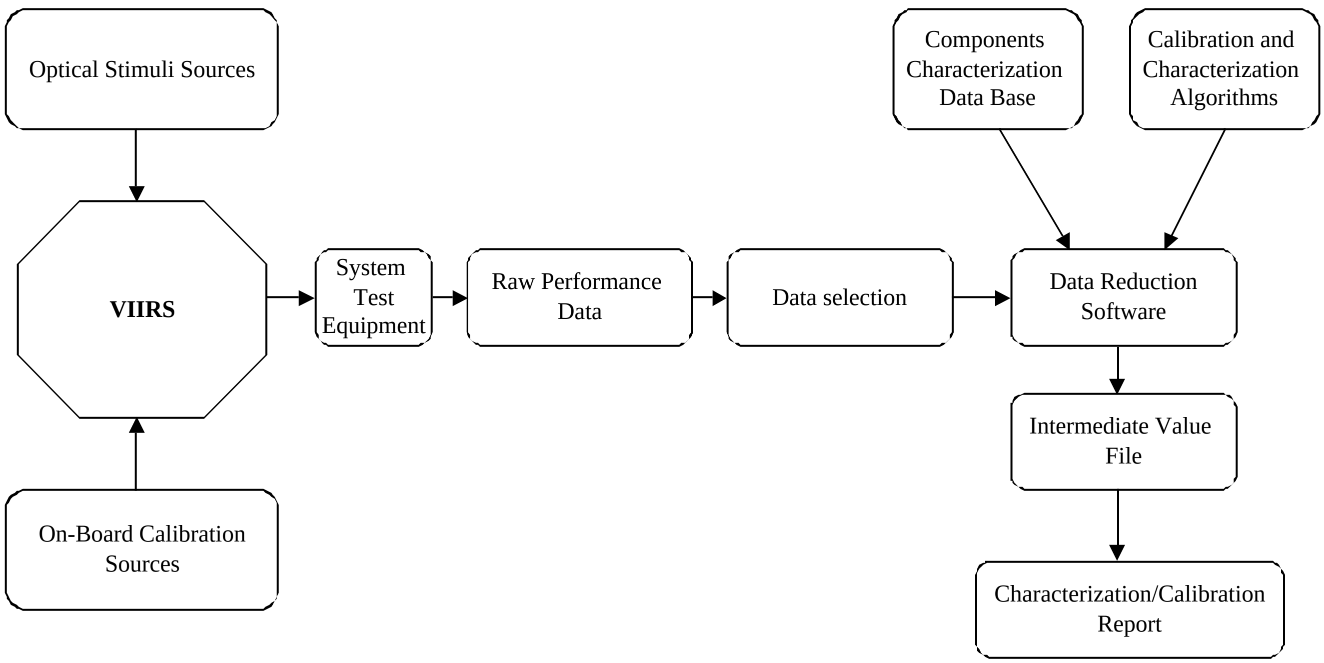

Figure D-1: Typical Performance Test Plan Flow Diagram

A performance characterization and calibration results database for each VIIRS instrument evolves as the instrument goes preflight, on-orbit testing, and operational usage. The database is used to check for internal inconsistency throughout the instrument lifetime. A multi-instrument database permits inter-instrument comparisons.

D.2.1 Calibration Sources

The preflight calibration includes the calibration of both VIIRS sensor and the on-board calibrators using traceable laboratory measurements.

A large Spherical Integrating Source (SIS) is used to perform the radiometric calibration of the visible (VIS), near infrared (NIR) and short wavelength infrared (SWIR) bands of the sensor. The medium-wavelength infrared and long-wavelength infrared (LWIR) will use a full aperture blackbody calibration source (BCS). These two sources will be separately calibrated with standards traceable to NIST primary standards.

On-board sources/stimuli include full-aperture blackbody, Solar Diffuser (SD) with attenuation screen, and Solar Diffuser Stability Monitor (SDSM) integrating sphere and filtered detectors will also be calibrated so that an accurate comparison of calibration accuracy between ground and on-board calibrators can be established.
Where appropriate, source calibration will be traceable to NIST standards or other standards while subsystems, such as monochromators, will be spectrally characterized using standard calibration techniques. The calibration sources and the associated parameters requiring calibration are presented in the table below.

Table D-1: Calibration Sources and Associated Parameter Requiring Calibration

Calibration sources and equipment	Parameters requiring calibration
Spherical Integrating Sphere (SIS)	Spectral radiance, degree of polarization, spatial uniformity, rate of change of spectral radiance as a function of current change, temporal stability.
Integration and alignment collimators (IAC)	Effective focal length, image quality, Modulation Transfer Function (MTF), distortion, reticles-spatial phase, translation stage characterization, optical alignment.
IAC radiometry	Spectral radiance, polarization effects, spatial uniformity, ungula uniformity, spectral radiance versus lamp current, temporal stability.
Spectral measurement Assembly (SPMA)	Spectral effects: spectral slit width, solid angle-area product, wavelength calibration, reference detector calibration.
Full aperture Blackbody calibration source (BCS)	Emissivity, temperature, thermal uniformity across the BCS surface, temperature gradients across paint layer, spectral radiance.
Rotary indexing table	Rotational angle calibration
Scattering Measurement Assembly (SCMA)	Transmission of neutral density filters, astigmatic image alignment.
Polarization Source Assembly (PSA)	Internal alignment, co-alignment of PSA optical axis with rotation axis,, degree of polarization, polarization uniformity across exit beam
Space View Source (SVS)	Temperature sensors.

Calibration and characterization of the test equipment is necessary to permit removing test equipment induced effects from the VIIRS calibration measurements.

D.2.3 Calibration Methodology and Processing

The requirements for the VIIRS sensor are given in the Sensor Specification for the VIIRS, document number PS 154640-101.

The VIIRS calibration will have four components:

- Absolute radiometric calibration for uniform background
- Absolute radiometric calibration for structured background
- Instrument level short-term stability monitor
- Instrument level long-term stability monitor

D.2.4 Absolute Radiometric Calibration

Absolute radiometric calibration and the associated uncertainties and stabilities will be verified by analysis, modeling, and/or simulation. The process of satisfying the radiometric calibration requirements against both uniform and structured backgrounds will be accomplished through instrument characterization using National Institute of Standards and Technology (NIST) standards to the extent possible. The radiance levels applied to the calibration process will be based on flow-down requirements for the EDRs based on measuring top-of-the-atmosphere radiance levels.
Achieving total sensor accuracy is not simply a matter of obtaining good calibration standards, but one of identifying and controlling the numerous physical and environmental factors that ultimately limit measurement accuracy. Experience in sensor calibration has taught much about identifying sources of uncertainty and learning how to control them. For most bands, sufficiently accurate standards exist, but calibration of a total sensor, on the ground and in orbit, includes multiple transfer standards, auxiliary optics, and test instabilities that individually can be sources of error many times larger than the standard itself.

Blackbody sources are used in thermal vacuum chambers for calibration in the MWIR and LWIR. There are no equivalent reflectance region standards to use. The driving parameters in blackbody calibration accuracy are temperature and cavity emissivity. Temperature standards exist through NIST and have reported accuracies of <0.01 K – more than sufficient to meet VIIRS requirements as long as a uniform temperature field can be obtained in the cavity. However, knowledge of cavity emissivity is more difficult since it depends on the emissivity of the cavity coating material (as measured on a flat witness sample), the cavity shape, and the validity of assumptions about how well the coating in the cavity can be simulated by the same type of material coating a flat witness sample. A model for the SBRS Blackbody Calibration Source (BCS) was developed by SBRS for MODIS that incorporates many of these effects. To verify this model at the level of uncertainty relevant for VIIRS, a NIST portable transfer radiometer as described in

Section 4.5 and Appendix C will be used to measure the in-situ radiance from the BCS in the SBRS calibration chamber at a number of BCS temperatures.

D.2.5 Calibration Stability

For less than 2 weeks, short-term calibration stability will be addressed using three approaches:

- The continuity of calibration data obtained during laboratory calibration tests,
- Monitoring the on-board calibration blackbody source (OBC),
- On-orbit calibration data from Solar diffuser (SD) together with the Solar Diffuser Stability Monitor (SDSM).

Long-term calibration stability for duration in excess of two weeks will be addressed by monitoring the SD and comparing it to the SDSM measurements. The On-Board Calibrator (OBC) blackbody will also be used to monitor the long-term calibration stability, in addition to the lunar calibration.

D.2.6 Multiple independent measurement approaches

The VIIRS calibration will be accomplished through three interrelated techniques:

- Laboratory characterization/calibration of the sensor
- Extensive on-board calibration using the sun, internal sources and the moon
- Comparison with the ground truth.

Confidence in the precision and accuracy is accrued by iterative use of these interrelated calibration methods.

Preflight calibration for the sensor and on-orbit calibrators is itself a series of repeated tests. Initial calibration is done in a clean-room ambient environment, and is then repeated after environmental qualification (vibration and shock) tests, during thermal vacuum tests, and finally after thermal vacuum. The stability of the trends in the data continuity is used in assessing the VIIRS preflight calibration validity.

The advantage of the in-flight calibration over pre-flight calibration is that it will account of the actual, not simulated, operational environment of the sensor. The goal of the in-flight calibration is to measure the changes between pre-flight and on-orbit calibration, to update the associated calibration coefficients when necessary, and to provide the continuity in these data for the lifetime of the mission.

D.2.7 Reflectance Band Calibration

A preliminary setting of the gain and offset is obtained using the Spherical Integration Source (SIS). The on-orbit calibration update is accomplished by viewing the Solar Diffuser. The error allocation is independent of the radiance level and hence of DNEV. The predominant error source arises from uncertainties in the reflectance of the solar

diffuser, BRFSD, which is taken as 1.6% for bands below one micron. The RMS allocation for all the terms is 2.0%.
Clearly, the solar diffuser BRF is the principal source of error. The errors introduced by variation in the focal plane temperature are insignificant if the temperature is measured with a 0.1 K accuracy.

The angle of incidence error is the next largest error contributor. Flat fielding is a potential problem because small systematic errors occur if an incorrect normalization is applied. The remaining errors are generally insignificant.

D.2.8 Emissive Band Calibration

A Blackbody Calibration Source (BCS) and the Space View Source (SVS) are used to calibrate the radiometric response of the VIIRS sensor. The BCS temperature calibration accuracy is traceable to NIST. The on-board calibration (OBC) blackbody radiance is made traceable to NIST standards by comparing it to the BCS. Maintaining the VIIRS calibration relies on the long-term stability of OBC.

The BCS provides the principal reference standard of spectral radiance energy for the MWIR and LWIR (3.75 to 14.3 µm) bands. During ambient testing, the MWIR/LWIR relative instrument response vs. scan angle will be measured with the VIIRS instrument on the rotary table. The VIIRS will view the BCS and the SVS. The SVS will rotate with VIIRS, while the BCS will remain stationary.

The vacuum calibration is the primary radiometric calibration. The VIIRS system allows for viewing the full dynamic range with background illumination present in the vacuum environment.

Appendix E: CrIS Instrument Characterization and Calibration Tests

E.1 Spectral Calibration Using a Gas Cell

One technique for measuring gas transmittances for spectral calibration is to use a simple gas cell coupled to a variable temperature blackbody. The following procedures illustrate the simple radiometric measurements that could be made with CrIS in the laboratory to form accurate gas transmittances. Similar tests were used successfully with EOS-AIRS and verified that both the instrument line shape function width and centroids were within specification. Four measurements per transmittance spectrum are needed:

- Empty cell, warm black-body source, _ R^{BB}warm
- Empty cell, hot black-body source, _ R^{BB}_{hot}
- Gas in cell, warm black-body source _ R^{gas}_{warm}
- Gas in cell, hot black-body source _ R^{gas}_{hot}

where *R* could either be a calibrated radiance or just the Fourier Transform of a raw interferogram, as long as stable instrument conditions are maintained. It is easily shown that the gas cell transmittance is then given by

$$\tau_{gas} = (R^{gas}_{hot} - R^{gas}_{warm})/(R^{BB}_{hot} - R^{BB}_{warm})$$

If *R* is not calibrated, then τ_{gas} is actually the real part of the right-hand-side of the equation. Notice that τ_{gas} is independent of the transmission of the gas cell optics. A gas cell that is nominally 100/50 cm long and pressure of 10/20 torr of gas will suffice.

This test does not require an accurate blackbody (windows can be used in the optical path), just a stable one. The hot blackbody temperature should be set to the maximum allowed by the CrIS detector chain. The warm blackbody temperature should be set to approximately halfway between the hot blackbody temperature and room temperature.

These tests permit both the wavenumber scale factors and geometrical dependencies of the ILS to be determined as described below:

<u>Wavenumber Scale</u>. A single wavenumber scale-factor will be determined for each detector channel using reasonably long dwell-time observations to minimize noise. The process involves:

* Calibrate and co-add CrIS radiances for the gas-filled cell, assuming a nominal wavenumber scale for each detector (based on nominal laser and optical alignment parameters)
* Interpolate to a dense spectral point spacing by performing double FFTs with zero-filling in the interferogram domain, and

* Determine the ratio of the line center of a calculated spectrum to the observed line center.

This ratio is the desired scale-factor adjustment factor that establishes the wavenumber scale calibration for the entire spectral band of each detector. Any scale-factor adjustments that exceed expectations based on laser and optical alignment tolerances should be investigated.

The final radiance data processing for CrIS will use these scale-factors to perform a normalization of the spectral scale for each individual detector to a chosen standard spectral scale.

Instrument Line Shape: The difference of gas cell observations, with and without gas in the cell, can be used to refine knowledge of the ILS for each detector. Here the process involves:

- Calibrate, co-add and difference CrIS radiances for the gas cell observations, with and without gas in the cell,
- Select a localized spectral feature, zero-fill in the spectral domain, and FFT to the interferogram domain to obtain a densely sampled interferogram,
- Normalize the interferogram amplitude with the amplitude observed in the Zero Path Difference (ZPD) region, and
- Compare the dependence of the local maxima of the interferogram on Optical Path Difference (OPD) to that of a calculated spectrum to determine the Self Apodization for the observed spectral feature.

These test results should establish the geometrical parameters needed to correct for self-apodization. Any substantial deviations from expectations should be investigated.

Appendix F: ATMS Instrument Characterization and Calibration Tests

F.1 ATMS Pre-Launch Characterization and Calibration

The pre-launch characterization and calibration of ATMS will rely heavily on the thermal vacuum calibration program, supplemented by more thorough measurements at ambient pressure and multiple temperatures, as discussed below. Some measurements should be performed on all flight instruments, and some only on an engineering unit or a single flight unit, as discussed below.

F.1.1 ATMS Temperature Sensitivity (NEDT)

Temperature sensitivities, referred to the antenna aperture, will be determined for all flight instruments for the following conditions:

1. The antenna should view a nominal 293 K isothermal blackbody target that fills the field of view (including reflectors),
2. The bandpass characteristics, nominal instrument temperature, and integration times should be the same as expected during inflight operation,
3. The calibration procedure should be the same as for nominal inflight operation,
4. The procedure should be sufficiently lengthy that further measurements would not alter the results by more than 0.01K rms.

F.1.2 ATMS Bandpass Characteristics

The bandpass characteristics for each channel should be measured and documented over the extreme operational temperature range to be encountered in space; two or three temperatures would normally suffice, and thermal vacuum would normally not be required. The accuracy should be sufficient to ensure that no indicated brightness temperatures would depart by more than 0.1 K (goal) from that expected for any reasonable atmospheric profile solely as a result of incorrect or incomplete pre-launch bandpass characterization. This is most difficult for those spectral bands where the radiance depends strongly on frequency. One standard procedure is to measure the instrument response to a calibrated swept-frequency generator radiating into the instrument antenna in order to reveal standing-wave resonances in the antenna/receiver structure. In the absence of resonances sufficient to threaten the 0.1K objective, a calibrated swept-frequency generator can feed the receiver at the waveguide antenna port. Ten equally spaced frequency samples within each passband and ten adjacent, five above and five below, should normally suffice, as should rms relative accuracies of 0.3 dB. Each flight model should be measured at its antenna port for all frequency-sensitive channels unless two ATMS instruments demonstrate sufficient inter-unit consistency.

F.1.3 ATMS System Linearity

The amplifiers and detectors in sensitive radiometers often exhibit non-linearities that threaten calibration accuracy at antenna temperatures removed from those of the two calibration loads. Tests should be performed to ensure that such compensated non-linearities will introduce less than 0.1K calibration error under the most challenging plausible combinations of antenna and instrument temperature. One standard procedure is to measure in the laboratory the relation between the radio frequency (RF) intensity and the output counts by using a broadband thermal RF source in series with an extremely well calibrated variable attenuator. Small non-linearities are most easily detected at the highest signal levels. To the extent that the system gain may vary in orbit, these measurements assume increased importance.

A second type of non-linearity is "gain stealing" or "channel cross-talk" that can occur when a single non-linear broadband amplifier amplifies two or more spectral passbands (channels). Bench measurements using broadband thermal signals should ensure that the worst case cross-talk will not introduce more than 0.1K uncompensated errors for any plausible changes in on-orbit channel characteristics. If cross-talk levels are found to be more than 10 dB below the 0.1K threshold for all shared-amplifier channels for the first instrument, then the need for testing additional instruments diminishes. Related tests of the instrument should verify that changes in any one channel's intensity does not alter any other output, as can happen if the post-detection circuits are insufficiently isolated.

F.1.4 ATMS Calibration

ATMS is calibrated every scan cycle in space using cold space and an unheated blackbody load. Calibration errors in ATMS-like prior instruments have generally been dominated by: bandpass variations (see 4.4.2), non-linearities (see 4.4.3), unknown blackbody emissivities below unity, temperature gradients within the calibration blackbody, errors in blackbody temperature sensors, variations of instrument response with calibration switch position (in ATMS this is the position of the scanning mirror), and angle- and situation-dependent contributions to antenna temperature due to the Earth/space boundary, spacecraft, sun, and moon. Most of these potential error sources can be measured and compensated pre-launch using thermal vacuum calibration tests, laboratory measurements, and antenna range measurements. Each of these sources of calibration error should be measured so that uncompensated contributions to calibration error from each are less than ~0.05 K rms, a level that helps ensure cumulative errors less than ~0.2 K rms.

Blackbody emissivities can be evaluated in the laboratory by comparison with a known "perfect" blackbody standard or by reflectivity measurements using strong signals in a reflection-free environment. Errors due to temperature gradients are more easily minimized by blackbody design than by measurement, and measurements in thermal vacuum are generally required for final evaluation. The external calibration blackbody used in thermal vacuum must therefore be of extremely high quality and well coupled to the antenna at its multiple view angles. Any flight model not undergoing such thermal vacuum tests should be calibrated in a similar manner at standard pressure. The PRT and similar temperature sensors should be traceable to NIST standards and accurate to 0.05 K. Antenna-angle-dependent errors can be measured in part with external “perfect” blackbodies that fill the view to space and capture all antenna sidelobes. Errors can originate if the antenna reflects signals transmitted by the RF pre-amplifier in an initial mixer-preamplifier in a scanning way. Error contributions from the Earth/space boundary, spacecraft, sun, and moon can be evaluated using antenna pattern measurements (see 4.4.5) and appropriate environmental models.

F.1.5 ATMS Antenna Pattern Measurements

Accurate antenna patterns are needed to (1) facilitate the image sharpening made possible by Nyquist sampling, and (2) assess and correct the scan-angle dependent sidelobe contributions to brightness temperature error. The uncompensated brightness temperature error, to the extent possible, should always be less than 0.1K. These errors are most critical for channels 52.8-58 GHz and are most serious when the sidelobes have significant amplitude and large-scale structure near the planetary limb. The patterns for at least one flight unit should be measured at least at the center frequency of each channel. The sensitivity of these antenna pattern measurements should permit accuracies of 2 dB rms at absolute antenna gains 20 dB below isotropic, which implies a dynamic range of at least 65 dB (TBR) for the narrow beams, essentially free of antenna-range-wall and surface-reflection effects. The rms accuracy of the absolute pattern measurement should otherwise generally be no worse than the less restrictive of 3 percent in absolute gain or 0.5 dB (TBR), and the rms precision should be one-fifth of that.

For each pattern the two principal axes of the nadir beam should be scanned at least $\pm 90^{o}$ at increments no greater than one tenth of the 3 dB beamwidth. For one of the channels above 140 GHz and one channel below, nadir patterns should also be measured for both polarizations along lines 45^{o} removed from the principal axes. For the antenna pointed approximately 40^{o} to one side, antenna patterns for both principal polarizations (referenced to Earth) of the 31.4 GHz and 53.6 GHz channels should be measured over 180^{o} of scan (over the nominal Earth view), and two such patterns should also be obtained for scans at $\pm 45^{o}$ to the principal axes. Several ATMS channels are affected by surface emissivity, which varies with view angle and polarization. Because ATMS mixes both polarizations, a 1^{o} misalignment of polarization angle could introduce an angular asymmetry across the full scan of approximately 1 K, comparable to that observed near 23 and 31 GHz for AMSU on NOAA 15 and NOAA 16 (alternate explanations for asymmetry include unexpected antenna sidelobe asymmetries or pointing errors). This angle should be measured +/-0.2 degrees (goal) on-axis for the antenna pointed +/-40 degrees from nadir. Greater pattern measurement accuracy and more complete mapping than suggested here would be helpful

F.1.6 ATMS Polarization Angle Alignment

ATMS has several channels with temperature weighting functions peaking in the lower troposphere or below the surface. These measurements are affected by surface emissivity. Over oceans, the emissivity varies with view angle and polarization. Therefore, the observed ATMS radiance for these channels displays an angular dependence although the

ATMS measures a mixing signal from both vertical and horizontal polarization. A small misalignment of the polarization angle would result in an asymmetric radiance across the scan lines. The asymmetric radiance along the scan line was first identified from NOAA-15 AMSU and continued to be present for NOAA-16 AMSU. The adverse impacts of the asymmetry on AMSU derived atmospheric and surface products manifest some false features such as asymmetric cloud liquid water across the scan line. The empirical scheme was developed over the oceans where the surface emissivity can be accurately simulated.

The AMSU asymmetry could be a combination of several causes: (1) polarization angle alignment; (2) antenna pointing angle; and (3) an intrusion of the solar array. The initial analyses for NOAA-15 and -16 AMSU show that the adjustment of -1.5 degree to the instrument polarization angle is needed in order to eliminate the asymmetry. Thus, the Government Team needs to monitor the ATMS pre-launch calibration procedure including the polarization angle alignment. It is recommended that the angle be accurate to a few tenths of a degree.

Appendix G: Surface Based Networks / Field Campaigns Relevant to NPP Cal/Val

G.1 Introduction

This appendix gives information on the various field observations relevant to the NPP calibration/validation efforts, including routine observations from surface based networks and observations from intermittent field campaigns. Note that there are other resources required for the NPP efforts (such as NIST calibration facilities, numerical model data, data from other satellites,…) which are not covered here; this appendix addresses field data only.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) is a joint NASA, NOAA, and DOD program merging the current POES & DMSP systems into a common system of polar satellites with the goal of providing meteorological and other environmental data products operationally. The Earth Observing System (EOS) is an international multi-satellite program for global remote sensing of the Earth, with a mission goal to advance the scientific understanding of the Earth system (i.e., including land, oceans, and atmosphere) as well as the influences of natural and anthropogenic processes on this system. In order to achieve these goals, these programs must produce accurate and precise long-time series of radiometric measurement data from multiple instruments on multiple platforms. Understanding and correctly interpreting these data require the ability to separate geophysical variability from instrument response changes in the observed signal during the missions. This requires a detailed instrument system-level characterization pre-launch, as well as extensive in-flight calibration and validation activities.

Validation is the process of assessing by independent means the uncertainties of derived geophysical data products from instrument system outputs. This is generally approached by direct comparison with independent correlative measurements from ground-based networks, comprehensive test sites, and field campaigns; along with comparisons with independent satellite retrieval products from instruments on the same and different platforms. Pre-launch activities usually focus on algorithm development and characterization of instrument uncertainties, while post-launch emphasis is on algorithm refinement and measured/retrieved data product assessments. It is essential to have an integrated strategy for validation, including contributions from airborne field campaigns, surface networks, as well as satellites. LEO satellites provide measurements within a spatial context, while surface networks bring in the temporal context; airborne field measurements, however, provide both spatially & temporally registered observations from a configuration geometry (i.e. nadir viewing) similar to the space-based sensor being validated. Multi-platform observation campaigns can provide simultaneous radiometric and geophysical parameter measurements over spatially and spectrally homogeneous Earth scenes enabling validation of the on-orbit satellite radiometric calibration as well as geophysical parameter retrieval validations. The overall goal is to enable a timely assessment of data product uncertainty for the new space-based sensor being validated.

In order to validate global atmosphere and surface properties derived from NPP satellite data, a reasonable sampling of the global variability of these products is necessary. Given that each NPP product may vary widely in space and time, most of the difficulty in validating the global products arises from sparse sampling of the range of values encountered by each variable. Hence, the NPP validation strategy includes not only focussed field campaigns in specific locations and under specific environmental conditions, but also a long time-series of selected measurements from a select distribution of **surface validation sites**. The primary surface validation sites promoted for use by NPP are those currently also being used by EOS. This allows for continuity in the validation data used to assess both the EOS and NPP products. Required site/network instrumentation and measurements are specific to each discipline (atmosphere, land, ocean, cryosphere, clouds, and aerosols). Such networks include, for example, AERONET, the ARM CART sites, the EOS Land Validation Core sites, the international radiosonde network, and MOBY sites.

To supplement the routine observations taken at the various surface sites and to extend the range of observation variability, the NPP validation will benefit from additional key observations collected during intermittent **field campaigns**. These campaigns can take many forms and include both pre- and post-launch experiments, aimed at both algorithm and product validation. As with many recent campaigns, most of the experiments should be conducted in the context of larger science objectives, while also leveraging the campaign for NPP satellite validation. The experiments should be oriented toward providing a larger spatial context for the routine, on-going observations made at the surface networks, while also covering a larger range of conditions (surface types, temperature, air mass, clouds, …) not observed at the routine sites. Other experiments with specific, targeted validation goals are also envisioned. These campaigns will often involve high altitude aircraft based sensors, as well as profiling aircraft, ship based cruises, and additional surface based sensors. The IPO developed NAST suite of aircraft sensors and similar sensors including S-HIS and MAS (for example) which provide NPP-like radiometric observations, will be used. These and other in-situ, remote sensing, and active sensing observations can provide the proper spatial and temporal context needed for satellite validation. The higher spectral and spatial resolution data can be spectrally and spatially convolved, respectively, to simulate what should be measured by the concurrent satellite observations during overpass events.

The successful validation of NPP measurements will require the utilization of many resources, some of which are supported by agencies or countries outside of the NPP. Some of the resources are extant now, but may not be at the time they will be needed for the NPP activities, and it is incumbent on the NPP to endeavor to ensure the continued existence of these vital assets in to the NPP era. In addition to the sensors and instrument networks that will be required, there is also the need to nurture the expertise in the scientific community so that this will be available to make the appropriate contributions to the validation exercise.

The remainder of this appendix lists specific networks and aspects of field campaigns desired for NPP validation. Where appropriate, the resources are divided into the six disciplines: atmospheric sounding, land, ocean, cryosphere, clouds, and aerosols.

G.2 Surface Based Networks

Surface based networks provide long term, continuous sources of validation data, often providing for a wide range of observed parameter space, and large sample sizes and statistics required for validation. The NPP validation sites are chosen to have significant overlap with those of EOS and similar programs, to provide for continuity in the scientific assessment of satellite products. Intrinsic to the NPP validation activities are sites around the globe where there are specific concentrations of appropriate sensors, such as the ARM sites, as well as networks of individual sensors. Many of these sites can be used to validate several EDRs and CDRs and over several of the discipline groups, such as oceanic and atmospheric variables. Table G-1 lists many of the larger existing networks, primarily suited to the validation of atmospheric variables. Other sites include, for example, BigFoot, LTER, MPLnet, the BSRN/SurfRad network, CMDL sites, and MOBY.

Table G-1: Networks and Web Sites Associated with Global Climate Change

Acronym	Source	Status / Location	Data ?	# sites
Field Campaigns and Focused Studies				
ARM	Atmospheric Radiation Monitoring Program (NSA, AAO, SGP, TWP)	http://www.arm.gov/docs/index.html	Yes	5
BigFoot	BigFoot	http://www.fsl.orst.edu/larse/bigfoot/index.html	Yes	5
Intensive Field Campaign	Field Campaigns: FIFE, BOREAS (NSA,SSA), LBA, S2K, SNF, HAPEX-Sahel, OTTER, Miombo	Mostly in ORNL DAAC	Yes	13
Long-Term Research Sites				
LTER	US LTER	http://www.lternet.edu/	Yes	22
Monitoring Networks				
FLUXNET	FLUXNET	*http://daacl.esd.ornl.gov/FLUXNET*	Yes	140
FLASK-NET	Cooperative Air Sampling Network	http://www.cmdl.noaa.gov/ccgg/flask/ccgnetwork.dat	Yes	80
AERONET	Aerosol Robotic Network	http://aeronet.gsfc.nasa.gov:8080/	Yes	230
BSRN	Baseline Surface Radiation Network	http://bsrn.ethz.ch/wrmc/bsrn_mainframeset.html	Yes	33
ISIS	Integrated Surface Irradiance Study	In process. http://zepher.atdd.noaa.gov/isis/isis.htm	?	0
NADP	National Atmospheric Deposition Program/National Trends Network	http://nadp.sws.uiuc.edu/	Yes	266
TRAGNET	Trace Gas Network	http://www.nrel.colostate.edu/PROGRAMS/ATMOSPHERE/TRAGNET/TRAGNET.html	Yes	25
Global-Scale Demonstration Networks				
VALCORE	EOS Land Validation Core Test Sites	Mercury	Soon	24
VCC/VCF	MODLAND Land Cover Change: Vegetation Cover Conversion (VCC) and Vegetation Continuous Fields (VCF)	In process. http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/products/vcc_vcf.html#ref	?	0

G.2.1 Surface Networks Supporting Atmospheric Sounding

ARM Sites

ARM, the Atmospheric Radiation Measurement Program, was initiated by the U.S. Department of Energy (DOE) with the ultimate goal of improving the parameterizations of clouds and radiation used in climate models.

Programmatic Objectives are: (1) to relate observed radiative fluxes and radiances in the atmosphere, spectrally resolved and as a function of position and time, to the temperature and composition of the atmosphere, specifically including water vapor and clouds, and to surface properties, and sample sufficient variety of situations so as to span a wide range of climatologically relevant possibilities; (2) to develop and test parameterizations that can be used to accurately predict the radiative properties and to model the radiative interactions involving water vapor and clouds within the atmosphere, with the objective of incorporating these parameterizations into general circulation models.

Figure G-1 show the location of the three ARM sites considered in the NPP calibration and validation plan

Figure G-1. Locations of the NSA, SGP, and TWP ARM sites.

The ARM sites (www.arm.gov) are well established resources that are expected to make important contributions to the validation of primarily atmospheric variables. They include the following sensors: up-looking infrared spectrometers (AERIs), mm cloud radars, uplooking microwave radiometers, GPS, Raman LIDARs, balloon-bourne sensors (radiosondes) launched at the satellite overpass times, sun-photometers, MFRSRs and a full suite of surface meteorological measurements including up- and down-looking broadband radiometers. In addition to the three standard sites which each have the potential to contribute validation data in three distinct climate regimes, there is a need for comparable data taken in other conditions, and this can be achieved by using a mobile ARM site, which was planned at the outset of ARM program and which may become a reality in the NPP timeframe. ARM data are available through the ARM Archive at ORNL (www.arm.gov/archive).

Oceanic atmospheric measurements

For validation over the oceans, comparable sets of instruments are available on ships, such as the *Explorer of the Seas* which undertakes a weekly cruise circuit between Miami and the US Virgin Islands (see www.rsmas.miami.edu/rccl). An extensive suite of instruments has been installed on research ships for specific campaigns, such as on NOAA's *Ronald H. Brown* for the Nauru99 expedition, which also involved coordinated measurements from the Japanese RV *Mirai* and the ARM site on Nauru (see http://www.arm.gov/docs/news/nauru99/).

International Radiosonde Network

Making good forecasts first requires that we have measurements of wind speed and direction, temperature, pressure, and humidity everywhere in the atmosphere simultaneously.

In practice, this is impossible. However, getting the best set of observations will help forecast the weather with more accuracy as far into the future as possible.

The main device used to measure the state of the atmosphere above the Earth's surface is the radiosonde, a balloon-borne package of instruments that measure temperature, pressure and humidity as the balloon ascends from the Earth's surface through the troposphere and well into the stratosphere. In addition, as the radiosonde rises, it can be tracked visually or by radar to provide information about the winds aloft. (In that case, it is sometimes called a rawindsonde.)

The radiosonde balloon expands continuously under ever-lower pressure as it floats upward, until ultimately it pops, releasing the package of instruments with a parachute back to the surface.

To get measurements throughout the atmosphere, an international network of radiosonde stations is maintained by countries around the world. The network for North America comprises stations typically 200-400 miles apart on land.

There are virtually no radiosonde stations over the oceans except on occasional islands and a few specially equipped ships, which makes forecasting for the West Coast of North America difficult because our winter storms (midlatitude cyclones) generally come from the west, from over the Pacific Ocean, where there are few detailed observations of the state of the weather. China maintains a denser radiosonde network than North America does, but many poorer parts of the world, like the oceans, lack good coverage, making good forecasts there very difficult.

To get approximately simultaneous observations throughout the atmosphere, radiosondes are launched twice a day from each station in the international network, at 00Z and 12Z (that is, at 5:00 P.M. and 5:00 A.M. PDT, or 4:00 P.M. and 4:00 A.M. PST). Each radiosonde transmits its measurements to the launch station on the ground, whence they are forwarded to a central location for analysis. (In the U.S., that location is the National Centers for Environmental Prediction, or NCEP, outside Washington D.C.).

SuomiNet

SuomiNet is a proposed network of GPS receivers to be located at universities and other locations to provide realtime atmospheric precipitable water vapor measurements and other geodetic and meteorological information. Detail on this network facility and equipment can be found in this URL: http://www.unidata.ucar.edu/suominet/

ECC Ozone Sondes

The ozonesonde is a lightweight, balloon-borne instrument that is mated to a conventional meteorological radiosonde. As the balloon carrying the instrument package ascends through the atmosphere, the ozonesonde telemeters to a ground receiving station information on ozone and standard meteorological quantities such as pressure, temperature and humidity. The balloon will ascend to altitudes of about 115,000 feet (35 km) or about 4 hPa before it bursts. The heart of the ozonesonde is an electrochemical concentration cell (ECC) that senses ozone as is reacts with a dilute solution of potassium iodide to produce a weak electrical current proportional to the ozone concentration of the sampled air.

The CMDL network of eight ozonesonde sites makes weekly ozone vertical profile observations from the surface to about 35 km using electrochemical concentration cell (ECC) ozonesondes. Three of these sites, Boulder, Colorado, Hilo, Hawaii, and South Pole, Antarctica have records of at least 15 years in length covering a significant portion of the period that stratospheric ozone has been declining. There are about 50 locations around the world that make regular (approximately weekly) ozone vertical profile measurements using ozonesondes. More details are located at this URL: http://www.cmdl.noaa.gov/

G.2.2 Surface Networks Supporting Land and Atmosphere Properties

Aeronet

The AERONET (AErosol RObotic NETwork) program is an inclusive federation of over 100 ground-based remote sensing aerosol networks. AERONET provides hourly transmission of CIMEL sunphotometer data (spectral aerosol properties and total water vapor) to the GOES (or METEOSAT) geosynchronous satellites, which in turn relay the data to GSFC for daily processing and archiving. By teaming with AERONET, MODLAND scientists have access to validation data from a global network of CIMELs in near real-time. The Aeronet network will be the main source of atmospheric characterization for MODLAND Validation activities. AERONET data are on-line at *http://aeronet.gsfc.nasa.gov:8080.*

FLUXNET
The FLUXNET network is dedicated to long-term measurements of carbon dioxide, water vapor, and energy exchange from a variety of worldwide ecosystems, integrated into consistent, quality assured, documented data sets. FLUXNET is a network of networks, which integrates worldwide CO_2/H_20 flux measurements through the ASIAFLUX, AmeriFlux, CARBOEROFLUX, and Oznet networks. There are currently over 140 towers registered with FLUXNET and over 60 of these have submitted data or defined a start date for doing so. The Oak Ridge DAAC will be the point of contact for FLUXNET data archive and distribution. Details on FLUXNET can be found at *http://daacl.esd.ornl.gov/FLUXNET/*.

Land – EOS Core Sites
To provide the *in-situ* and other reference data, NPP land validation program will utilize the EOS five-tiered categorization of field site measurement capabilities and intensity (TableA-1).

The EOS Land validation Core Sites are being used for MODIS Land validation program, and will provide the science community with timely ground, aircraft, and satellite data for NPP science and validation investigations. The sites, currently 24 distributed worldwide, represent a large range of global biome types, and roughly comprise the area within 100 km radius of a center point (http://modis-land.gsfc.nasa.gov/val/coresite_gen.asp). (Figure G-2).

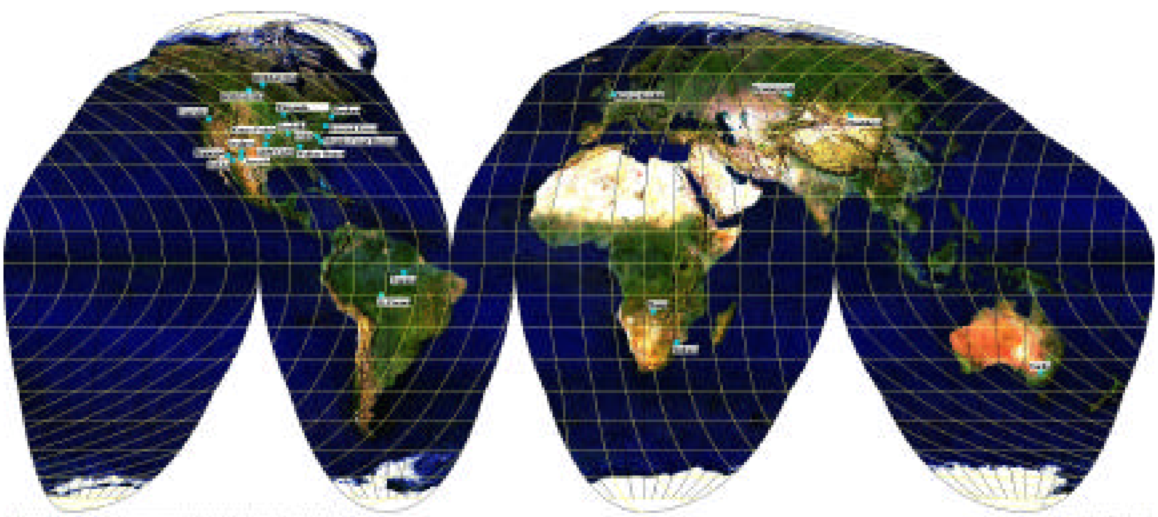

Figure G-2: EOS core sites (24 sites) located in North America, South America, Europe, South Africa and Australia. Detailed information for each site can be found at this URL http://modis-land.gsfc.nasa.gov/val/coresite_gen.asp.

In most cases, each EOS site includes a fixed tower on which above-canopy instrumentation will be mounted to provide near-continuous sampling of canopy-scale radiometric and meteorological variables. A conceptual model for a core site instrument package includes a CIMEL™ ground and sky-scanning sun-photometer (surface reflectance, vegetation index, BRDF), albedometers (albedo), and a CO_2 flux system. These data are augmented by surface measurements of LAI and FPAR at less frequent time intervals. Core Sites will receive priority deployment of validation instrumentation and cover each major biome type delineated in NPP operational and science algorithms.

Table G-2 provides a description of the EOS sites and data types collected. EOS core validation test sites. Detailed information on the surface measurements and airborne data at each site can be found in http://modisland.gsfc.nasa.gov/val/coresite_gen.asp

The EOS validation program is planning to continue its collaboration with the NASA's Airborne Science Program (http://www.dfrc.nasa.gov/airsci), which provides airborne platforms to carry NASA sensors such as AVIRIS, MAS, MASTER and AirMISR.
A new airborne system developed for MODIS vegetation reflectance and vegetation index validation called MODIS Quick Airborne Looks (MQUALS) (http://gaea.fcr.arizona.edu/validation/index.htm), carrying digital cameras, a radiometer and albedometer is being used over EOS sites.

A selection of product specific validation data performed at the EOS core sites is described in the Table G-3.

Data collected at these validation sites, over a large number of field campaigns are available through Mercury system at the ORNL DAAC (Cook et al., 1999). The Mercury system performs a key role in centralizing the distribution and archiving of field data, and provides both the team collecting the data and the users significant advantages relative to traditional data management systems (http://mercury.ornl.gov).

Table G-2: EOS core validation test sites

Site Name	Biome	Coordinator	Latitude	Longitude	Tower (Network) *
ARM/CART	Agriculture	Meyer	36.64	-97.5	YES(B, F, G)
Bondville,IL	Agriculture	Meyers	40.01	-88.29	YES(A, B)
BOREAS, NSA	Boreal Forest	Baldocchi	55.88	-98.48	YES(A, B, F)
BOREAS, SSA	Boreal Forest	Baldocchi	53.98	-105.12	YES(A, F)
Cascades	LTER Evergreen	Forest Running	44.5	-121.62	YES(A, B, F, G)
Harvard Forest	Decid. Forest	Baldocchi	42.37	-72.25	YES(B, F, G)
Howland	Decid. Forest	Baldocchi	45.3	-68.8	YES (A, F, G)
Ji-Parana	Trop. Forest	Huete	-10.22	-61.89	Planned
Jornada Huete	LTER	Shrubland	32.5	-106.75	YES (G)
Konza	Prairie Grassland	Baldocchi	39.08	-96.62	YES (F, G)
Krasnoyarsk	Forest	Murphy	56.5	92.5	YES
Maricopa Ag.	Agriculture	Huete	33.04	-111.58	None
Mongu	Woodland	Privette	-15.45	23.25	Planned (A, G)
SALSA	Desert shrub /grassland Montagne forest	Huete	31.74	-109.85	None
Sevilleta LTER	Desert/grassland	Holben	34.32	-106.8	None (A)
Skukuza	Savanna	Privette	-25	31.67	YES (A, G)
Tapajos	Trop. Forest	Huete	-3.23	-54.75	Planned
Uardry	Grassland	Hook	-34.39	-145.3	None
Ulan Bator	Grassland	Huete/Honda	45.75	106.26	None
USDA ARS	Agriculture	Liang	39.03	-76.85	YES(A, F)
Virginia Coast	Coastal Area	Justice/Vermote	37.5	-75.67	None (A)
Walker Branch	Decid. Forest	Baldocchi	35.9	-84.3	YES(F, G)
Wisc. LTER	Forest	Norman	46	89.6	YES(F)

*A= AERONET, B = Bigfoot, F=FLUXNET, G = Global Land Cover Test Sites

Table G-3: MODIS land products and instrumentation data used for validation

Product	Field Instrument	Airborne	Satellite data
Surface Reflectance	Hand held Radiometer,	MQUALS, MAS, AirMISR, AVIRIS	MODIS, MISR
Land Surface Temperature	Thermal Infrared Spectrometer, Spectral Infrared Bidirectional Reflectance and Emissivity, Heinman Thermometer	MAS, MASTER	ETM+, ASTER, MODIS
Snow and Sea Ice	Field Survey, NOHRSC	MAS	ETM+, ASTER, MODIS
BRDF*/Albedo	Albedometer (Kipp+Zonen CM21) BSRN	AVIRIS	MISR, MODIS, VEGETATION, MODIS
Vegetation Index	Spectrometer	MQUALS, MAS	ETM+, MODIS,
LAI/FPAR*	LAI-2000, TRAC, Field ceptometer, Spectrometer	MAS	ASTER, MODIS
PSN/NPP*	CO2 flux towers		MODIS
Fire and Burn Scan	Field survey	MAS	TM, ETM+, MODIS
Land Cover	Field survey	AVIRIS, MAS	IKONOS, MODIS
VCC/VCF*	Field survey	AVIRIS, MAS	IKONOS, MODIS

* BRDF: Bidirectional Reflection Distribution Function
LAI: Leaf Area Index PSN: Daily Photosynthesis
NPP: Net Primary Production VCC: Vegetation Cover Conversion
VCF: Vegetation Continuous Field

G.2.3 Ocean Surface Networks

Ocean surface networks include both fixed location time series sites and spatially and temporally varying cruise data sets. The former includes systems like MOBY and perhaps other sites supported by the international ocean color community, e.g., a MERIS calibration buoy in the Mediterranean Sea and a NASDA-supported buoy for GLI validation. Shipboard bio-optical data collected by the international SIMBIOS science team is being delivered to the SIMBIOS project and is available for VIIRS validation and algorithm development.

Marine Optical BuoY (MOBY)

The validation of oceanic retrievals in the visible part of the spectrum will be carried out principally using the Marine Optical BuoY (MOBY) sites off Hawaii, and using MOCE cruises (Marine Optical Characterization Experiment) initialization cruise. MOBY's primary purpose is to measure visible and near-infrared radiation entering and emanating from the ocean. It is the variations of the visible region-reflected radiation that is referred to as ocean color from which other quantities can be derived, such as the abundance of microscopic marine plants (phytoplankton).

Approximately 50 feet long, MOBY is the world's largest marine optical device. In the ocean, only its antennae, solar panels, strobe light, and surface buoy (which houses the computer and cellular phone for data transmission) are visible, standing about 7 feet above the waterline. A fiberglass mast extends more than 40 feet directly down beneath the buoy to the instrument bay. At depths of about 6, 16, and 28 feet respectively, 9-foot long booms or "arms" extend outward perpendicular to the mast.

Optical collectors (irradiance and radiance) have been placed at the ends of the arms, as well as on top of the buoy above the surface to collect light coming into the ocean, and then the light reflected back out of the ocean. The reflected portion of the light has been modified by particles such as phytoplankton suspended at various depths, that modifies the signal available to the satellite sensors. Lenses within these collectors focus the light onto fiber optic cables which then transmit the light to a fiber optic multiplexer housed in the instrument bay. The multiplexer relays the light into a dual spectrograph with detectors that measure the spectral radiant energy. These signals are then digitized and relayed by microprocessors and transmitted up to a main computer housed in the surface buoy. This information is then stored on a disk drive, which may be accessed via cellular phone and downloaded for processing back at the MOBY Team facility.

The optical system uses two spectrographs with a dichroic ("water") mirror to measure radiometric properties with high spectral resolution and stray light rejection. This "water" mirror is designed to transmit the red (630 to 900 nm) and reflect the blue (380 to 600 nm) portions of the spectrum, making the transition from reflectance to transmittance between 590 and 650 nm. Thus potential for stray light is greatly reduced by splitting the visible spectrum at the beginning of the water absorption region since most of the short wavelength energy is diverted from the entrance slit of the long wavelength spectrograph. The splitting also allows the spectrographs (free spectral range and integration times) to be optimized for the two distinctive spectral domains. Internal calibration and ancillary sensors (temperature, inclination, pressure, etc.) are included.

Ocean - SST

The validation of SST derived from VIIRS and CrIS/ATMS requires the use of infrared radiometers or interferometers accurate to better than 0.1K. These are mounted on ships so that they measure the skin temperature of the ocean ahead of any influence of the vessel. The primary instrument for this is the M-AERI, which operates in the range of infrared wavelengths from ~3 to ~18μm and measures spectra with a resolution of ~0.5 cm^{-1}. It uses two infrared detectors to achieve this wide spectral range, and these are cooled to ~78°K (i.e. close to the boiling point of liquid nitrogen) by a Stirling cycle mechanical cooler to reduce the noise equivalent temperature difference to levels well below 0.1K. The M-AERI includes two internal black-body cavities for accurate real-time calibration. A scan mirror directs the field of view from the interferometer to either of the black-body calibration targets or to the environment from nadir to zenith. The mirror is programmed to step through a pre-selected range of angles. When the mirror is angled below the horizon the instrument measures the spectra of radiation emitted by the sea-surface, and when it is directed above the horizon it measures the radiation emitted by the atmosphere. The sea-surface measurement also includes a small component of reflected sky radiance. The interferometer integrates measurements over a pre-selected time interval, usually a few tens of seconds, to obtain a satisfactory signal to noise ratio, and a typical cycle of measurements including two view angles to the atmosphere, one to the ocean, and calibration measurements, takes about five minutes. The M-AERI is equipped with pitch and roll sensors so that the influence of the ship's motion on the measurements can be determined. The radiometric calibration of the M-AERI is done continuously throughout its use. As with simpler self-calibrating radiometers, an FTIR spectroradiometer can be calibrated by using two black-body targets at known temperatures. These provide two reference spectra to determine the gains and offsets of the detectors and associated electronics. A fuller description is given by Minnett et al, 2001.

Other simpler, filter radiometers are capable of achieving the required accuracy and can be used to extend the data set achieved by the M-AERIs (of which three currently exist). These are the CIRIMS, ISAR, SISTeR, DAR011 and the JLP Nulling Radiometers which all participated in the Infrared Radiometer Intercomparison held in Miami in the summer of 2001 (see http://rsmas.miami.edu/ir2001). Several of these sensors belong to foreign investigators or groups, and their participation in NPP validation campaigns may require special arrangements.

Comparison with *in-situ* measurements of the ocean temperature taken below the surface from ship or buoys, moored and drifting, can contribute to the validation of NPP SSTs provided they are limited to moderate wind speed conditions (<~6ms^{-1}) where the relationship between the subsurface bulk temperature and the surface skin temperature is moderately well constrained (Donlon et al, 2001). At lower wind speeds, the vertical temperature gradients are sufficiently variable that they decouple the skin surface temperature from the bulk measurement at a depth of centimeters and more, at least at the accuracy of 0.1K that is required for SST validation (Minnett and Ward, 2000; Ward and Minnett, 2001).

Ocean Color

We recommend that NOAA sponsor a dedicated NPP initialization cruise, dedicated to characterization of the NPP EDR's and CDRs (especially ocean color and SST), in the first several months of the mission, in which members of the cal/val team can participate and collect a complete initialization and validation data set. The objectives would be to enable complete characterization of the atmosphere and ocean relevant to NPP. For ocean color and ocean bio-optics, the SeaWiFS Protocols document gives a good listing of variables which should be measured and techniques that should be employed. For SST, results of the round-robin calibration workshops conducted at U. Miami serve as an excellent framework for skin radiance measurements.

The objectives would be to enable complete characterization of the atmosphere and ocean relevant to NPP. For ocean color and ocean bio-optics, the SeaWiFS Protocols document gives a good listing of variables, which should be measured and techniques that should be employed.

A dedicated initialization cruise is recommended because it is not possible to obtain all the measurements for complete characterization of the ocean and atmospheric optical properties and pigments. These detailed observations allow a complete analysis of the radiative transfer calculations for vicarious calibration, atmospheric corrections, and bio-optical algorithms (especially semi-analytic algorithms), and, therefore, provide quantitative estimates of all radiometric processes. Accommodating such and extensive suite of observations in not possible as a piggyback on other cruises because of conflicting requirements for lab space, hydrographic winches, and berths. However, limited bio-optical and atmospheric data from cruises of opportunity are quite useful for product validation, i.e. direct comparisons.

We recommend that NOAA sponsor a dedicated NPP initialization cruise, dedicated to characterization of the NPP EDR's and CDRs (especially ocean color and SST), in the first several months of the mission, in which members of the cal/val team can participate and collect a complete initialization and validation data set. The objectives would be to enable complete characterization of the atmosphere and ocean relevant to NPP.

Within NASA, planning is underway for an integrated global carbon cycle research program in conjunction with a federal interagency climate research initiative, which would be underway during NPP. An initial phase of an interagency collaboration on the carbon cycle would be an experiment to quantify the North American carbon budget. Such a program would include cruises in both coastal areas and the North Pacific and Atlantic from which VIIRS validation data would be collected. A second field program would be in the Southern Ocean.

References for Ocean Surface Observations

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Minnett, P.J. and B. Ward. Measurements of near-surface ocean temperature variability – consequences on the validation of AATSR on Envisat. ERS – ENVISAT Symposium “Looking down to Earth in the New Millennium” Gothenburg, Sweden. 16-20 October 2000.

Ward, B. and P. J. Minnett, 2001. An autonomous profiler for near surface temperature measurements. Gas Transfer at Water Surfaces. edited by M. A. Donelan, W.M. Drennan, E.S. Saltzmann and R. Wanninkhof. American Geophysical Union Monograph. In the press.)

G.2.4 Cryosphere

Need more here on routine cryosphere surface sites

In-situ measurements of cryosphere surface parameters are available from a limited number of sites, including Dome C and the North Slope of Alaska ARM site.

Dome Concordia (Dome C) is a broad topographic dome roughly centred at 75° 06’06”S, 123° 23’42”E on the polar plateau of East Antarctica (at 3233 m elevation a.s.l.), and is situated more than 700 km from the coast. This location is about 65 km south of the old U.S. Dome C camp, and has been selected as the optimal site for a new collaborative European (EPICA) deep ice core [Tabacco and others, J. Glac, 2000]. The chosen core site will allow recovery of a core to a depth of 3250m with a climate history of some 400,000 years. In conjunction, the French and Italians have agreed to cooperate in the establishment of a research programme, including construction and operation of a scientific base “Concordia”. The use of this station for scientific research is open to the world-wide scientific community and is considered here as a candidate calibration site for SMOS.

This site is well suited for cal/val activity for the following reasons:
1) homogeneity of snow surface at the 100 km scale
2) topography is known from satellite altimetry to high precision at 100km scale
3) surface roughness is minimal relative to other ice sheet locations
4) the sky is clear, and the atmosphere is extremely dry and stable
5) ionospheric activity is minimal (and daily and long term variation in Total Electron Content is minimized)
6) snow accumulation is low (around 3.7cm/yr).

The Dome C Site is well characterized, with:

- 10 years of consistent automatic weather station data (air temperature, pressure, wind speed and direction)
- Topography is known at the kilometric scale (from ERS geodetic phase altimetry and GPS measurements), and ICESAT will provide meter accuracy laser profiles over Dome C in 2001-2002.
- Bedrock is mapped at the same kilometer scale using P-band ground-penetrating radar, by subtracting ice thickness (along profiles) from the detailed altimeter topographic profiles.
- Ice surface velocity field is characterized by ERS SAR interferometry, GPS, and DORIS tracking.
- Ice core data provides the mean snow accumulation rate, and density profile information
- Embedded thermistor strings provide firn temperature profile temporal variability.
- Ancillary data sets exist from microwave radar scatterometers (5 and 13.6 GHz), radiometers (5, 19, 22, 37, 85 GHz), and radar altimeters (13.6 GHz).

Further in-situ measurement activities are planned in the frame of the Concordia project.

Priority Objectives (for Science Definition Studies):

- Establish temporal and spatial variability in SMMR C-band Tb over Dome C, and establish time-space correlation statistics/length scales in this region and
- rms variability information (*this should be done in view of the SMOS temporal revisit which is possible at high latitudes).
- Establish seasonal variation in Tb due to seasonal temperature cycle
- Correct for temperature and investigate variation in emissivity (independent of physical temperature).
- Establish whether radiative transfer models for ice sheet can be generalized to L-band (is dense-medium theory still appropriate, or are simple approximations
- Establish whether the Dome C ice sheet target is stable enough to check for long term stability and drift in total power (i.e. calibration).
- Is Dome C appropriate as a distributed target for checking consistency of image reconstruction, by using known trajectories of target through the FOV (in incidence and azimuth – through simulated swaths).
- Can the stability of the ice sheet emission be used to test the consistency in reconstructed brightness temperatures (for a reasonably uniform radiator)
- Does radiometric anisotropy in the surface matter at L-band for this pixel scale? If so, extrapolate existing definitions of anisotropy from NSCAT/SSMI/QuikScat data to define modulation pattern (as a function of local incidence and azimuth angle), and define Tb trajectories and range of variability according to relative orbit swath direction relative to surface anisotropy.
- Can Dome C indicate what the averaging requirement is to achieve a known level of accuracy such as a 0.1 K criterion (i.e. defined reproducibility in Tb over time).

G.2.5 Clouds

ARM sites

In addition to facilities for atmospheric sounding, the ARM sites also possess state-of-the-art measurements of cloud properties. These are provided by sensors including a millimeter cloud radar, micropulse lidar, Vaisala ceiliometer, whole sky imager, and Raman Lidar.

See section G.2.1 for description of the ARM sites instruments available for cloud characterization.

FARS

The Facility for Atmospheric Remote Sensing is a permanent cloud research station located on the eastern edge of the University of Utah campus (40.77degrees North by 111.83 degrees East) on the bench of the Wasatch Mountains (1.52 km above mean sea level). It was established in 1987 with joint funding from the National Science Foundation and the University of Utah to house the Cloud Polarization (ruby) Lidar, and has steadily grown through the addition of state-of-the-art remote sensors, including a suite of radiometers, a 3.2-mm polarimetric Doppler radar (from NSF and U. Utah), and the dual-wavelength scanning Polarization Diversity Lidar (PDL, from the Department of Energy Atmospheric Radiation Measurement -ARM- program). Both the radar and the PDL are mobile units that have participated in major cloud research programs, such as the Project FIRE II and ARM program CART Intensive Observation Period field campaigns. The current specifications of this unique university-based facility can be found at the facility equipment link below.

Since its inception, FARS has been applied to the regular study of high-level cirrus clouds in support of basic research and the satellite validation effort of Project FIRE through its Extended Time Observations (ETO) component. As of this time, more than 2,000 hours of ruby lidar ETO data from high level clouds have been collected from FARS. Current support for FARS observations comes from NSF and NASA for basic cirrus cloud and FIRE ETO satellite studies, the NASA Atmospheric Effects of Aviation Project for aircraft contrail/cirrus research, and the DOE ARM program for multiple remote sensor cloud retrieval algorithm development. Data from FARS and the field campaigns also support cloud microphysical and radiative transfer modeling research components at the Department of Meteorology. More details on the instruments avaialble at this site can be found in this URL: http://www.met.utah.edu/ksassen/fars.html.

MPLnet

MPL-Net is a worldwide network of micro-pulse lidar (MPL) systems. MPL-Net is run by members of the Cloud and Aerosol Lidar Group in Code 912 at GSFC and is funded by NASA/EOS . Additional funding for research cruises at sea is provided by the NASA SIMBIOS project. The MPL is a single channel (523nm), autonomous, eye-safe lidar system originally developed at GSFC and is now commercially available. The MPL is used to determine the vertical structure of clouds and aerosols. The MPL data is analyzed to produce optical properties such as extinction and optical depth profiles of the clouds and aerosols.

The primary goal of MPL-Net is to provide long-term data sets of cloud and aerosol vertical distributions at key sites around the world. The long-term data sets will be used to validate and help improve global and regional climate models, and also serve as ground-truth sites for NASA/EOS satellite programs such as the Geoscience Laser Altimeter System (GLAS) on the ICESat spacecraft. (launch date Spring 2002).

MPL-Net is composed of NASA operated sites, incorporated sites from the ARM MPL network, and sites privately operated by researchers from around the world. Also, all MPL-Net sites are co-located with AERONET sunphotometers. Instrument calibrations and data processing for all sites are accomplished using techniques developed by our group over 7 years of MPL development and deployment.
In addition to the long-term sites, MPL-Net provides support for field experiments each year using MPL systems reserved for field use (land and ship based deployments possible).

More details on the instruments avaialble at this site can be found in this URL: http://virl.gsfc.nasa.gov/mpl-net/.

G.2.6 Aerosols

ARM sites
See section G.2.1 for description of the ARM sites instruments available for aerosol characterization.

Aeronet
See section G.2.2 for description of instruments available at Aeronet to measure spectral aerosol properties.

FARS
See section G.2.5 for description of FARS sites and instruments available to measure spectral aerosol properties.

EOS core sites
See section G.3.2 for description of EOS sites and instruments available to measure spectral aerosol properties.

G.3 Field Campaigns

To supplement the routine observations taken at the various surface sites and to extend the range of observation variability, the NPP validation will benefit from additional key observations collected during intermittent field campaigns. These campaigns can take many forms and include both pre- and post-launch experiments, aimed at both algorithm and product validation. As with many recent campaigns, most of the experiments should be conducted in the context of larger science objectives, while also leveraging the campaign for NPP satellite validation. The experiments should be oriented toward providing a larger spatial context for the routine, on-going observations made at the surface networks, while also covering a larger range of conditions (surface types, temperature, air mass, clouds,…) not observed at the routine sites. Other experiments with specific, targeted validation goals are also envisioned. These campaigns will often involve highaltitude aircraft based sensors, as well as profiling aircraft, ship based cruises, and additional surface based sensors. The IPO developed NAST suite of aircraft sensors and similar sensors including S-HIS and MAS (for example) which provide NPP-like radiometric observations, will be used. These and other in-situ, remote sensing, and active sensing observations can provide the proper spatial and temporal context needed for satellite validation. The higher spectral and spatial resolution data can be spectrally and spatially convolved, respectively, to simulate what should be measured by the concurrent satellite observations during overpass events.

Field experiment measurements are critical for inter-comparisons with satellite-based instrument data to help validate such sensors, and their corresponding geophysical retrieval algorithms and data products, and achieve confidence in their subsequently-obtained data products. The NPOESS sensors are tasked with providing an operational monitoring capability for EDRs to be measured globally. This requires the calibration/validation process to be applicable over the range of observations to be encountered, and thus requires field experiment programs to be implemented such that this extent in observation variability is addressed. Correspondingly, field experiment geographic location and temporal insertion must be selected to cover the range in surface characteristics (topography, emissivity, temperature), and seasonal atmospheric content (water vapor & trace constituents) and weather (clouds & precipitation) variability. To the greatest extent possible, field experiment locations should be collocated near existing surface instrumentation networks (such as the SGP & NSA CART sites) to bring in additional, previously-validated "ground-truth" data. Additionally, these ground site measurements (i.e. radiosonde and driftsonde launches and ground-based instrument recording times) need to be temporally coincident with times of NPP satellite overpasses (or in an Intensive Operating Period, IOP, mode) during these field experiment validation periods.

Field validation measurements from high-altitude airborne sensors are critical for successful space-based instrument validation, since only observations from such platforms can provide the proper spatial & temporal context needed as well as be used to simulate expected satellite measurements for the instrument being validated. The higher spectral and spatial resolution aircraft sensor data can be spectrally and spatially convolved, respectively, to simulate what should be measured by the concurrent satellite observations during overpass events. The much higher spatial resolution of the aircraft sensor data can play an important role in validating satellite-derived data products under the conditions of variable surface and atmospheric radiance (e.g., due to clouds) within the satellite sensor footprint.

NPP field campaigns will draw heavily upon the aircraft based sensors developed by NPOESS including NAST and S-HIS. Aircraft data is important to the NPP calibration and validation both before and after launch. Before launch, it will provide the means to demonstrate expected performance and to establish algorithm approaches that will work in the presence of actual atmospheric cloud conditions. After launch, it will form the basis for system validation. The NPOESS Airborne Sounder Testbed (NAST) is a suite of airborne infrared and microwave spectrometers, developed for the Integrated Program Office (IPO), that has been flying on the NASA high altitude ER-2 aircraft as part of the risk reduction effort for NPOESS. In addition to their stand alone scientific value, data from these airborne instruments have been used to simulate possible satellite-based radiance measurements, therefore enabling experimental validation of instrument system specifications and data processing techniques for future advanced atmospheric remote sensors. The NAST-I is a high resolution Michelson interferometer that derives its heritage from the non-scanning High resolution Interferometer Sounder (HIS) developed by researchers at the University of Wisconsin and serves as one important component of the NAST instrument suite. It scans the Earth beneath the ER-2 or Proteus with a nominal spatial resolution of approximately 0.13 km per km of aircraft altitude (i.e. 2.6 km from a 20 km ER-2 altitude) and within a cross-track swath width of about 2 times the aircraft altitude (i.e., ~46 km for the ER-2); its unapodized spectral resolution of 0.25 cm-1 within the 3.6 - 16.1 micron spectral range will enable experimental simulation of future infrared sounding instruments. NAST-M is the microwave component of NAST, currently with channels covering the 54 & 118 GHz oxygen bands; this microwave component enables atmospheric sounding in the presence of clouds. The Scanning High resolution Interferometer Sounder (S-HIS) is an angular scanning Michelson interferometer also deriving its heritage from the non-scanning HIS instrument. While initially developed for operation on an unpiloted aircraft, S-HIS has flown on both the NASA DC-8 & ER-2 platforms. NAST-I & -M have both participated in the Wallops98, CAMEX-3, and WINTEX field measurement campaigns, and S-HIS served as an integral part of both CAMEX-3 & WINTEX. The NAST & S-HIS are validated airborne sensors that are available to: support NPOESS sounding instrument (i.e., CrIS & ATMS) development & validation activities; serve as an EOS Validation Tool (e.g., AIRS, CERES, MODIS, MOPITT, & TES); provide mesoscale Earth science observations (from field experiment campaigns, e.g. CAMEX-3, WINTEX, and other flights of opportunity, e.g. Wallops98/99); as well as to serve as an engineering testbed for infusion of new technology (i.e., to explore enhancing airborne sounding; optimizing space-based sounding performance; and applicability toward other measurements, e.g. chemistry).

The primary focus of the combined NAST & S-HIS payload will be to provide upwelling infrared and microwave radiance measurements and retrieved geophysical parameters to assist with or enable the following:

- accurate, spatially & temporally registered infrared & microwave calibrated radiance spectra for observed Earth scenes
- detailed characterization of atmospheric thermal and moisture structure, under clear to cloudy conditions
- radiative trace gas detection & transport (e.g. O_3, CO, CH_4, N_2O, CO_2)
- biomass burning studies: atmospheric radiative impact; radiative temperatures of fires; and Earth scene type classification

- NPOESS IPO instrument and forward model pre-launch specification optimization and post-launch calibration/validation (e.g. CrIS & ATMS)
- EOS instrument and forward model calibration/validation (e.g. CERES, MODIS, MOPITT, AIRS, TES)
- NAST-I, NAST-M, & S-HIS instrument performance verification/calibration/validation
- synergistic retrieval studies (e.g., NAST-I + NAST-M, MAS + S-HIS), including other platform measurements, etc.)
- EOS & NPOESS follow-on sensors for T, H2O, & chemistry: instrument concept definition and optimization studies
- advanced Geostationary Earth Orbit (GEO) sounding & chemistry applications: instrument concept definition and optimization studies

The following radiance and geophysical data products may be obtained from field implementation of the NAST-I, NAST-M, and S-HIS instrument suite:

- calibrated radiances (IR & U-wave)
- atmospheric temperature profiles
- atmospheric water vapor profiles
- surface temperature & emissivity
- cloud properties (altitude, temp. & emiss., LWP, effective particle size)
- tropospheric species column concentrations & some profiling (e.g. ozone, carbon monoxide, methane, & water vapor)
- atmospheric transport via H2O winds
- aerosol IR optical depth

NAST-I & NAST-M have flown on NASA's high-altitude ER-2 aircraft and on the high-altitude profiling Proteus aircraft. S-HIS has flown the bulk of its time on the NASA DC-8 (i.e. during the CAMEX-3 field mission), while also having several flights on the ER-2 (i.e., during WINTEX). In addition to enabling flight opportunities when the ER-2 is booked, the Proteus has several beneficial flight attributes making it very attractive stand-alone or for flying combined sorties with the ER-2 during field deployments. The Proteus-unique platform attributes include:

- Ultra_fine and variable spatial resolution by not being constrained with a minimum flight altitude
- Improved geophysical data product quality with increased sample averaging afforded by slower ground speed
- Extended time observation capability of pollution episode evolution and transport processes with long duration flight capability
- Measurement altitude profiling capability using platform cruise altitude variations
- Further complementary benefits may be achieved by combining Proteus flights with ER-2 and DC-8 field deployments, including:
- Inter_platform validation capability
- Radiation Divergence (cooling rate) measurements via formation flying at different levels

- Enhanced total measurement set through combined instrument diversity
- Extend effective swath width of airborne remote sensing observations through offset formation flying
- Broader spatial scale coverage through varying simultaneous flight patterns

Many of these attributes are also provided by the S-HIS when flying onboard the profiling DC-8. Plans are also currently being made for NAST deployment on the GlobalHawk, an unmanned high altitude aircraft that would allow flight durations of up to 24 hours and global transits, allowing for spatial sampling similar to that of a single satellite orbit. Also possible in the NPP post-launch time frame is NAST-2, a NAST follow-on with additional observation capabilities.

G.4 Discipline Specific Field Campaigns

G.4.1 Atmospheric Sounding Field Campaigns

Piloted research aircraft (e.g., ER-2 and Proteus) carrying a variety of active and passive radiometric sensors will be used in field programs to provide high spatial resolution validation data. These aircraft will be capable of flying over wide range of altitudes, including vertical profiling which enables precise validation of radiative transfer models and retrieved atmospheric parameters. Unmanned airborne vehicles (e.g., the Global Hawk) will enable a global sampling of surface and atmospheric products over a wide range of geographical and atmospheric conditions in a single flight. Commercial aircraft equipped with meteorological sensors (e.g., ACARS) will provide time coincident atmospheric sounding validation data obtained during ascents and descents near airports around the globe.
Required scientific measurements and potential instrumentation include the following:

Measurement	***Sensor/Instrumentation***	***Platform***
IR spectral radiance	FTS/NAST-I, S-HIS, INTESA	high-altitude a/c
IR spectral radiance	FTS/AERI, MAERI	surface-based
H2O	LIDAR/LASE	high-altitude a/c
T, H2O, P (in-situ)	Radiosondes	balloon
H2O	LIDAR/SRL	ground-based
H2O	LIDAR/DIAL	ground-based
Microwave radiance	radiometer/NAST-M	high-altitude a/c
Vis/ir narrowband radiance	multispectral scanner/MAS	high-altitude a/c
Vis/ir narrowband radiance	multispectral scanner/MASTER	high-altitude a/c
Microwave radiance	imaging radiometer/PSR	high-altitude a/c
Vis/ir narrowband radiance	multispectral imaging/AVIRIS	high-altitude a/c
Vis/ir narrowband radiance	multispectral radiometers/MQUALS	high-altitude a/c
Vis imagery	multiangle imaging/AirMISR	high-altitude a/c
Vis/ir narrowband radiance	multispectral scanner/MODIS	satellite-based
Vis/ir narrowband radiance	multispectral scanner /ASTER	satellite-based
Vis/ir imagery	multispectral imaging/Landsat-7	satellite-based
Infrared spectral radiance	IR grating/AIRS	satellite-based

Infrared spectral radiance	IR FTS/IASI	satellite-based
Microwave radiance	radiometer/AMSU	satellite-based
Microwave radiance	radiometer/HSB	satellite-based
IR spectral radiance	FTS/GIFTS	satellite-based

Atmosphere – aircraft measurements

A series of sensors developed for deployment on aircraft is required for NPP validation of atmospheric variables, and some surface parameters too. These are the MAS, a fifty channel visible, near-infrared, and thermal infrared imaging spectrometer with 50 m resolution at nadir (King et al. 1996), the Scanning HIS, a 2 km resolution at nadir interferometer sounder, NAST-I, a 2.6 km resolution interferometer covering 3.5 to 16 microns with a spectral resolution greater than 2000, NAST-M, a 16 channel microwave radiometer sensitive to 50-60 and 113 -119 GHz radiation from 2.5 km resolution footprints, AVIRIS, a 224 band imaging spectrometer from 0.4-2.5 µm with 20 m resolution at nadir (Vane et al. 1993). All spatial resolutions cited above are for a NASA ER-2 aircraft altitude of 20 km. More information on the airborne instruments described above and others can be found at the URLs presented in Table A-3.

Additional Airborne Instruments include:

- Aircraft *in-situ* spectrometer for IR active trace gases at platform altitude
- Airborne LIDAR (i.e. LASE) for upper tropospheric H 2 O and aerosol profiles; co-incident observations with NAST-I/S-HIS would be invaluable to addressing H 2 O spectroscopic issues, particularly in the hard to measure upper troposphere.
- MAS for much higher spatial resolution to address small-scale scene variability
- FIRSC for far-IR measurements and cirrus cloud characterization
- MicroMAPS for measurements of layer integrated CO amounts
- MIR for microwave measurements of water vapor profiles

Atmosphere / oceanic measurements

For validation of over the oceans, comparable sets of instruments are available on ships, such as the *Explorer of the Seas* which undertakes a weekly cruise circuit between Miami and the US Virgin Islands (see www.rsmas.miami.edu/rccl). An extensive suite of instruments has been installed on research ships for specific campaigns, such as on NOAA's *Ronald H. Brown* for the Nauru99 expedition, which also involved coordinated measurements from the Japanese RV *Mirai* and the ARM site on Nauru (see http://www.arm.gov/docs/news/nauru99/).

G.4.2 Land Field Campaigns

The EOS land validation program is planning to continue its collaboration with the NASA's Airborne Science Program (http://www.dfrc.nasa.gov/airsci), which provides airborne platforms to carry sensors such as AVIRIS, MAS, MASTER and AirMISR.

A new airborne system developed for MODIS vegetation reflectance and vegetation index validation called MODIS Quick Airborne Looks (MQUALS) (http://gaea.fcr.arizona.edu/validation/index.htm), carrying digital cameras, a radiometer and albedometer is being used over EOS sites.

Data collected at these validation sites, over a large number of field campaigns are available through Mercury system at the ORNL DAAC (Cook et al., 1999). The Mercury system performs a key role in centralizing the distribution and archiving of field data, and provides both the team collecting the data and the users significant advantages relative to traditional data management systems (http://mercury.ornl.gov).

G.4.3 Ocean Field Campaigns

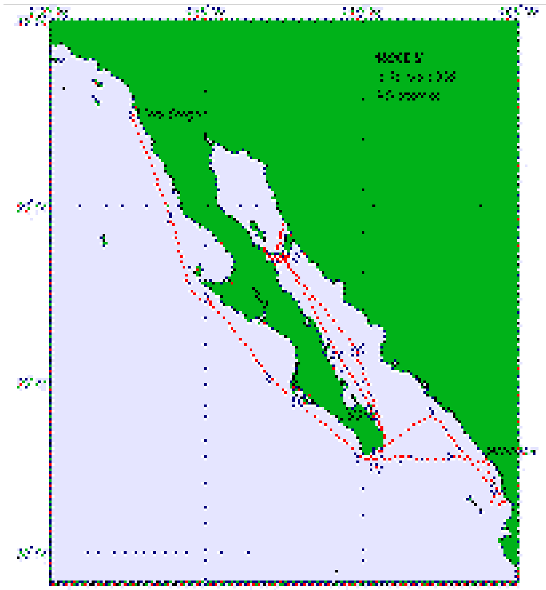
There are several approaches to validating the NPP oceanic EDRs and CDRs that vary depending on whether the ocean color, and derived variables, or surface temperature are concerned. The validating measurements for ocean color are taken primarily using sensors in the upper layer of the ocean, in the top tens of meters, whereas those for SST are taken primarily using radiometers from ships or aircraft. Ocean color validation requires the use of a specialized buoy (MOBY) or a ship which must stop to lower sensors into the water. SST validation data can be taken form a ship underway (e.g. Kearns et al, 2000) or from a low flying aircraft (e.g. Smith et al. 1994).

Dedicated cruises

For both color and temperature validation from ships it makes best use of resources if the cruise is in an area where clear skies can be expected, and where a large range of environmental variability, both oceanic and atmospheric, is to be experienced. An example of such a dedicated research cruise is the MOCE-5 (Marine Optical Characterization Experiment) that took place off Baja California in October 1999 (see http://orbit-net.nesdis.noaa.gov/orad/mot/moce/synopses/moce_5.html). The cruise track and surface temperature variability are shown in Figures G-3 and G-4.

Long transects - SST

Another approach to sampling a large variety of environmental variability is to mount radiometers on ships on transit across the oceans. Examples of such cruises in which M-AERIs have been used to provide measurements to validate AVHRR and MODIS SSTs is shown in Figure G-5. Several of the trans-oceanic sections are US Coast Guard icebreakers on their annual round trip between Seattle and Australia. Other such opportunities include the German icebreaking research vessel *Polarstern* on its route from Germany to the RSA, and the British ship RRS James Clark Ross that goes from the UK to Antarctica, via the Falklands each year (not shown). Other opportunities are research vessels en route between two areas of operations, such as the R/V *Roger Revelle* between Hawaii and New Zealand (purple track in Figure below).



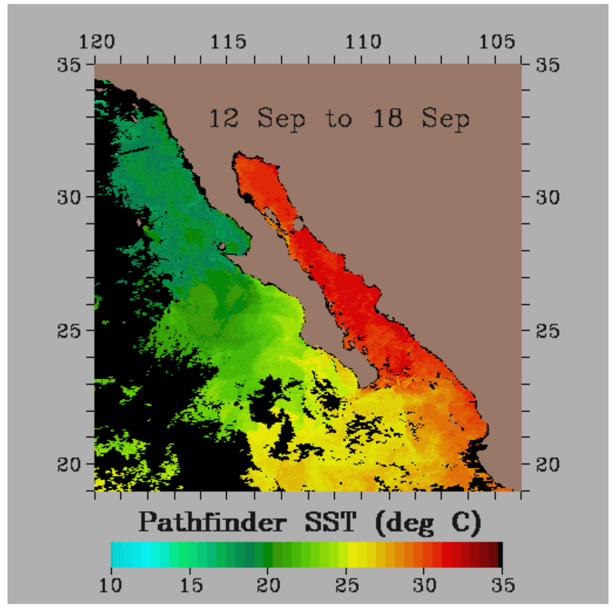


Figure G-3. Cruise track of the R/V Melville during the MOCE-5 cruise, 1-21 October 1999.

Figure G-4. SST field, derived from the AVHRR Pathfinder algorithm for area of the MOCE-5 cruise. Over 10K temperature changes exist in this relatively small area.

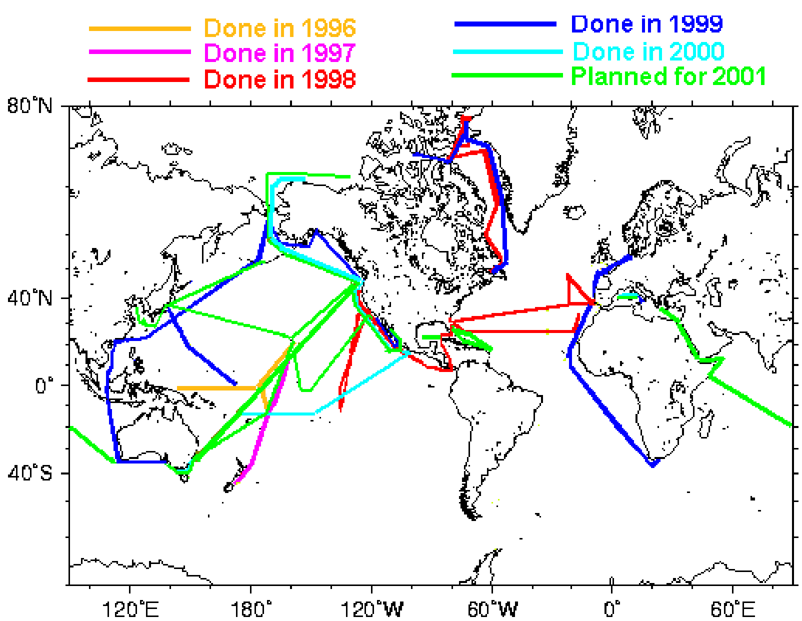


Figure G-5. Tracks of M-AERI cruises to provide SST validation data for AVHRR and MODIS during 1996 to 2001. Several trans-oceanic sections are of Antarctic supply vessels between the US and Australia or Germany and RSA.

Alternative vessels that may be suited to hosting SST validation radiometers are commercial vessels linking ports on different continents. In such cases, those that have a large latitudinal range rather than a wide longitudinal span are to be preferred because of the larger range of conditions to be expected. Also, to provide a more complete set of validation data it is necessary to include sensors for measuring the surface meteorological conditions and the state of the atmosphere at the times of the satellite overpasses.

Other cruises of opportunity include the summer research cruises into the Arctic on the US Coast Guard icebreakers each year, allowing validation data to be taken in extreme environmental conditions.

Process studies cruises

Further validation cruise opportunities are to be found in research ships of opportunity that will host the validation activities that compliment their primary objectives, (or at least not compromise them). These should be selected so that the full range of environmental conditions (atmospheric as well as oceanic) are sampled, and where other activities on the ship provide auxiliary data. Good examples of this are the Aerosol Characterization Experiment –ACE- cruises especially the ACE-ASIA cruise of 2001 (http://saga.pmel.noaa.gov/aceasia).

Repeated cruise tracks

A new approach to gathering oceanic validation data is to equip a cruise liner with state-of-the-art instruments that operate quasi-autonomously. Such ships are at sea for most of the time and provide a valuable platform for data gathering. The prime example of this is the *Explorer of the Seas* which follows a weekly track from Miami to St Thomas (Figure G-6).

Figure G-6. Weekly cruise track of the Explorer of Seas.

The instruments mounted on the *Explorer of the Seas* are shown in Figure G-7, and include an M-AERI and a full suite of meteorological sensors. Further details are at http://www.rsmas.miami.edu/rccl/facilities.html.

Another example of an instrumented ship doing repeat tracks is the *M/V Val de Loire*, a ferry that plies between the UK and Spain and which will carry a filter radiometer capable of measuring the skin SST to an accuracy of ~0.1K.

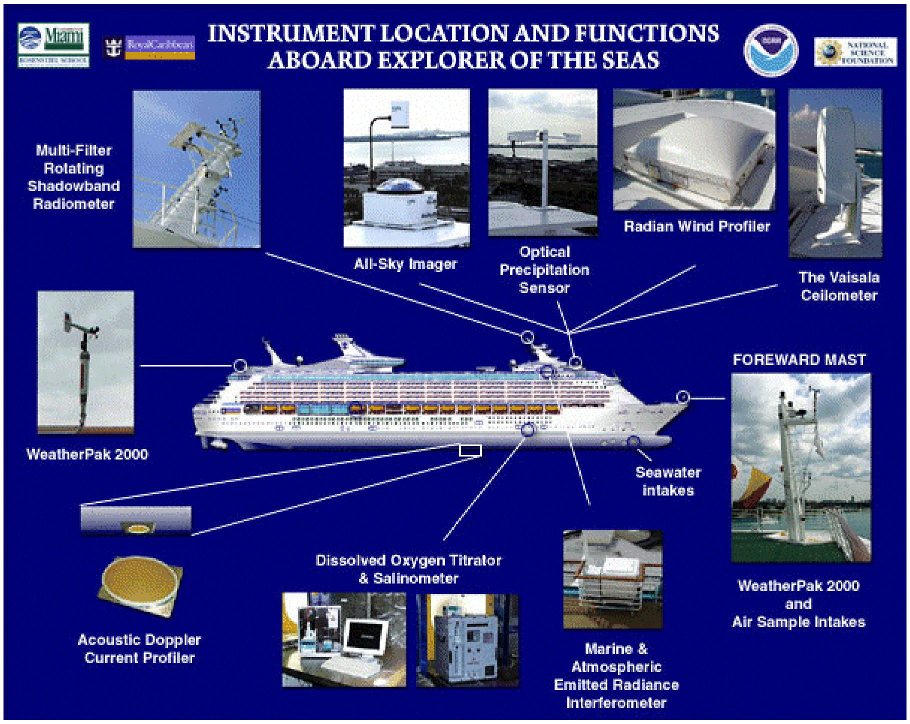


Figure G-7. Instruments on the *Explorer of the Seas.*

Multi-national campaigns

Multi-national oceanographic campaigns, such as those conducted under SIMBIOS project (http://simbios.gsfc.nasa.gov/) offer good opportunities for satellite validation as they often provide a concentration of instruments and expertise. Sometimes they include several ships and aircrafts, enabling the determination of the effects of spatial variability . As an example, the Nauru99, which involved the NOAA's *Ronald H. Brown*, the Japanese RV *Mirai,* the Australian Cessna 404 instrumented aircraft, and the ARM site on Nauru (http://www.arm.gov/docs/news/nauru99/). They also sometimes provide access to inhospitable parts of the ocean which otherwise remain out of reach, or difficult to access. An example of this is the North Water Polynya Project which took place in the Arctic, in the north of Baffin Bay in 1997-99; the cruise tracks for 1998 and 1999 are shown in Figure G-5. (See also http://www.fsg.ulaval.ca/giroq/now/).

Ocean Field Campaign References

Kearns, E. J., J. A. Hanafin, R.H. Evans, P.J. Minnett and O.B. Brown (2000). An independent assessment of Pathfinder AVHRR sea surface temperature accuracy using the Marine-Atmosphere Emitted Radiance Interferometer (M-AERI). Bulletin of the American Meteorological Society. 81(7): 1525-1536.

Smith, A.H., Saunders, R.W. and Zavody, A.M. (1994): The validation of
ATSR using aircraft radiometer data over the tropical Atlantic. J. Atmos.
Oceanic Technology, 11, 789-800

G.4.4 Cryosphere Field Campaigns

Because of the inhospitable environment and the logistical difficulties of operating in polar regions, the validation of the cryosphericR EDRs and CDRs will probably be limited to campaigns involving the aircraft sensors (for albedo and temperature) and opportunities to mount sensors on ice-breakers. *In-situ* measurements of snow depth at the ARM North Slope of Alaska site, at research bases in Antarctica and at Arctic meteorological stations can also be used.

NPP cold scene (<270 K) radiance calibration can be validated using P-AERI ground based measurements at the South Pole. P-AERI may be pointed upward to view zenith or downward to view surface or any angle in between. Because atmospheric water vapor concentrations over the South Pole are typically small (~5% relative humidity), slant path effects on NPP and P-AERI window band measurements will be small (<0.5°C). Importantly, P-AERI is capable of viewing the snow surface at the South Pole using the same viewing geometry as NPP. This will minimize surface effects on the calibration validation exercise. The combination of accurate skin temperature measurements, spatial homogeneity, very small atmospheric effects, and a large number of satellite overpasses make the South Pole PAERI deployment an essential validation tool for NPP CrIS and VIIRS.

G.4.5 Cloud Field Campaigns

Field campaigns which use aircraft and other ground based sensors to provide context to the routine surface site observations are required. Additional experiments which target observational conditions not normally encountered at the surface sites are also required. Aircraft based sensors include active cloud sensors (lidar, radar) and in-situ sampling devices.

G.4.6 Aerosol Field Campaigns

Field campaigns which use aircraft and other ground based sensors to provide context to the routine surface site observations are required. Additional experiments which target observational conditions not normally encountered at the surface sites are also required. Aircraft based sensors include active cloud sensors (lidar, radar) and in-situ sampling devices.

G.5 Future Experiments

Product validation for the NPP can be established on the basis of shared costs. While expenses associated with maintaining and fielding aircraft instruments can be significant, the requirements for IPO are compatible with those of ongoing NASA scientific programs, NOAA Calibration and Validation of its operational observing capabilities, NASA plans for EOS validation, and DOE field programs for climate studies. Plans are already in place from these and other organizations to support a substantial number of field programs that can be used to leverage IPO support. More specifically, NASA is conducting missions with these instruments throughout the current decade, including the SAFARI mission in South Africa in 2000, a joint water vapor experiment with the DOE centered around the Atmospheric Radiation Measurement (ARM) site in Oklahoma in 2000, Aerosol Characterization Experiments (ACE) in 2001, and a cirrus study with the Cirrus Regional Study of Tropical Anvils and Layers (CRYSTAL) in 2002 and 2004. NOAA will be conducting calibration validation of the operational polar orbiting infrared and microwave sounders periodically in the 2000s; intercalibration of the ongoing series of POES and EOS sensors and the associated imaging and sounding products is a high priority for these efforts.

There are several relevant field experiments and new instrument launches that will provide data for many of the activities in preparation for NPP calibration validation. They are presented in summary here and discussed in the various following sections in more detail (Table G-4, Table-5).

Table G-7 shows the NASA ER-2 flight schedules for FY02-FY06. current 5 yr schedule for both the ER-2 & DC-8 are available from http://www.dfrc.nasa.gov/airsci/er25yr.html. Specific field deployments for which the NAST/S-HIS package could significantly contribute toward both field mission science goals and EOS instrument validation include those listed in the following Tables.

Table G-4: NPP relevant field experiments and new instruments launches

Schedule *	Field Experiment
1Q01	TRACE P
2Q01	MCV
3Q01	CLAMS
4Q01	CHAMEX-4 AQUA LAUNCH ADEOS-II LAUNCH
1Q02	TERRA/AQUA CAL/VAL
2Q02	CLAP AIRS CAL/VAL
2Q02	IHOP
3Q02	CRYSTAL FACE MODIS AND AIRS CAL/VAL
4Q02	CHEM LAUNCH CHAMEX-4
1Q03	CHEM CAL/VAL
2Q03	MODIS AIRS CAL/VAL USWRP Gulf Experiment-Moisture Return Flow
3Q03	MODIS AIRS CAL/VAL AURA LAUNCH CRYSTAL
4Q03	EOS Cloud Radiation Forcing and Aerosol Feedback CAL/VAL
1Q04	CHEM CAL/VAL
2Q04	CRYSTAL USWRP Gulf Experiment-Moisture Return Flow
3Q04	CRYSTAL TWP
4Q04	METOP LAUNCH EOS Cloud Radiation Forcing and Aerosol Feedback CAL/VAL
1Q05	THORPEX
2Q05	SVWXEX
3Q05	TCEX GIFTS LAUNCH EOS Cloud Radiation Forcing and Aerosol Feedback CAL/VAL
4Q05	GIFTS CAL/VAL NMP EO-3 GIFTS Wind Profiling Validation Mission EO-3 GIFTS Chemistry Validation Mission
1Q06	NPP LAUNCH GIFTS CAL/VAL
2Q06	THORPEX
2Q06	GIFTS CAL/VAL
3Q06	CRIS/VIIRS/ATMS CAL/VAL GIFTS CAL/VAL EOS Cloud Radiation Forcing and Aerosol Feedback
4Q06	CRIS/VIIRS/ATMS CAL/VAL
1Q07	CRIS/VIIRS/ATMS CAL/VAL GOES, ABI and GIFTS CAL/VAL EOS Chemistry Mission

*** *NQYY*: N is the year quarter number, and YY is the year.**

Table G-5: List of references for field campaigns and programs relevant to NPP calibration validation effort.

Calibration and Validation Field Campaigns			
Name	**Reference URL**	**Principal Airborne Sensors**	**Primary Purpose**
SAFARI-2000	safari.gecp.virginia.edu	MAS, MQUALS,	Biophysical validation, LST, VI, Albedo, Aerosol, Fire
BOREAS	boreas.gsfc.nasa.gov/html_pages/boreas_home.html		Biophysical validation, LST, VI, Albedo, Aerosol, Fire
LBA	www-eosdis.ornl.gov/lba_cptec/indexi.html	MAS	Biophysical validation, LST, VI, Albedo, Aerosol, Fire
CLAMS	snowdog.larc.nasa.gov/cave/cave2.0/CLAMS.dir/index.html	NAST-I, NAST-M, MAS	
TRACE			
CRYSTAL			
THORPEX	www.nrlmry.navy.mil/~langland/THORPEX_document/Thorpex_plan.htm		
WINTEX	cimss.ssec.wisc.edu/wintex/wintex.html		
CAMEX	ghrc.msfc.nasa.gov/camex3/instruments/lase.html		
ARMCAS	ltpwww.gsfc.nasa.gov/MODIS/MAS/armcashome.html		Detect and differentiate between clouds, ice, and snow. Determine the scattering albedo of clouds
ACE-1 ACE-2	saga.pmel.noaa.gov/ace1.html www.ei.jrc.it/ace2		

Table G-6: NASA ER-2 schedule for FY00-FY03

Experiment	**Location**	**Instrument**	**Date**
CALVEX-M	CART/GMEX	MAS, CLS, S-HIS MOPITT-A (ER-2) NAST, FIRSC (Proteus)	Mar-Apr/00
SAFARI-2000	South Africa	MAS, CLS, S-HIS MOPITT-A (ER-2)	Aug-Sep/00
CRYSTAL	Guam	NAST, MAS, CLS, LASE, S-HIS	Jul-Aug 02
CAMEX-4	PAFB, FL	NAST, MAS, CLS, S-HIS	Aug-Sep 01

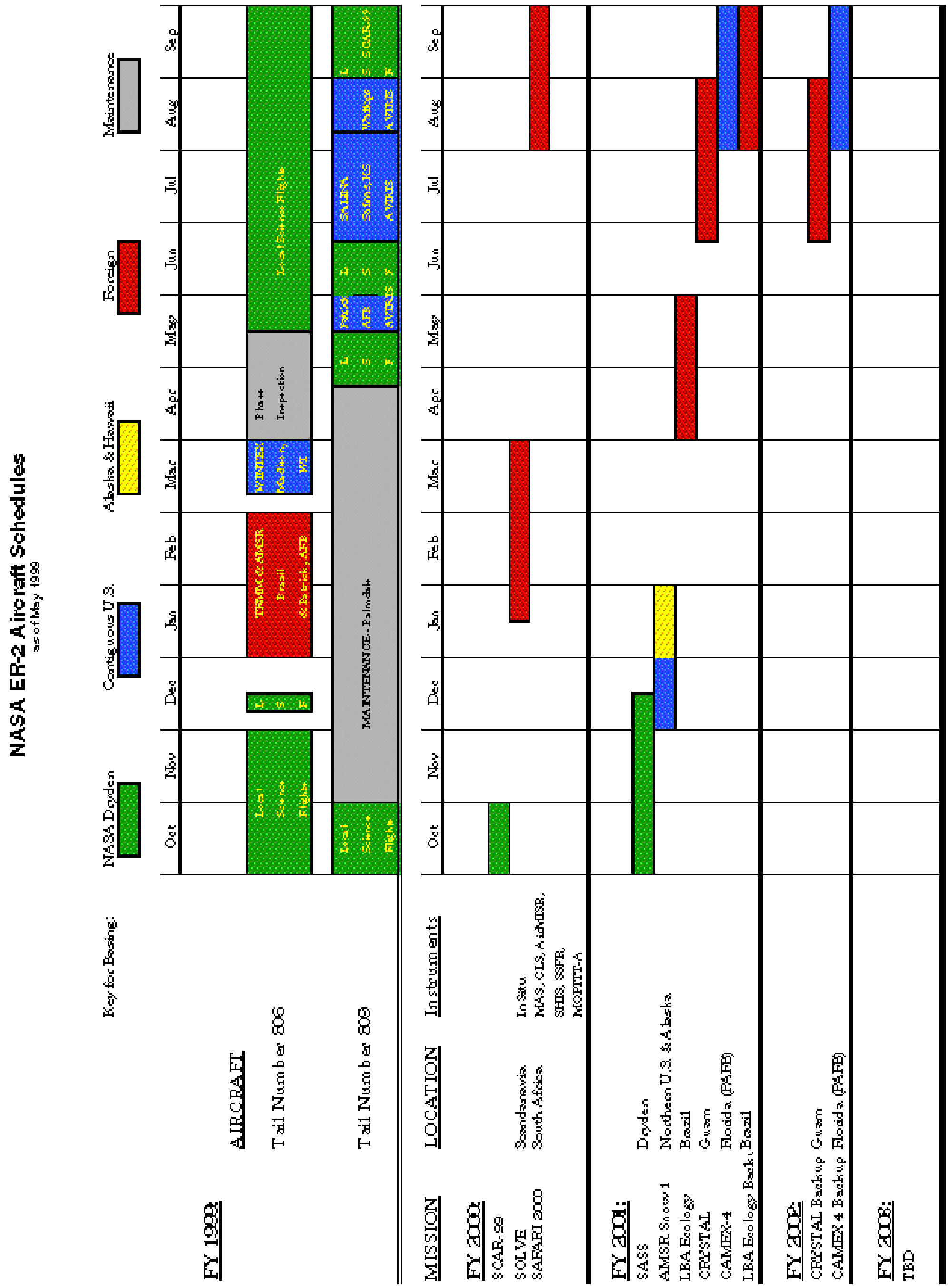


Figure G-7: Deployment schedule for NASA's high-altitude ER-2 aircraft.

Appendix H: EDR/CDRs Validation Specifics

This section provides a list of validation approaches considered in the NPP EDR/CDR product validation. It's an attempt to develop a priority sequence for each product validation from High priority to optional/low priority. For a specific EDR/CDR, approach listed as number 1 is high priority, and the last approach listed is optional or low priority.

Some EDR/CDR has as many as eight approaches considered for product validation. Only approaches with required funding will be implemented.

NPP validation approaches of the EDR (Section H.1) and the CDR (Section H.2) group of products (Atmosphere and sounding, Aerosol, Clouds, Ocean, Land, and Snow and Ice group) are presented in this Appendix.

H.1 Validation of the EDR Operational Products

H.1.1 Atmospheric Sounding Profiles

H.1.1.1 Atmospheric Sounding Profiles (Moisture, Temperature and Pressure) (Primary EDRs)

Approach 1: ARM Site Observations
Product:
Moisture, Temperature and Pressure Profiles (and integrated column water vapor)
Primary Validation Source:
Routine ARM site observations and dedicated NPP overpass radiosondes. (ARM site T/q best estimate).
Ancillary Data Sources:
GOES and Oklahoma Mesonet data for assessing spatial variability.
Technique:
The basic technique is to use the routine ARM site observations (at the Southern Great Plains site in central Oklahoma, at the North Slope of Alaska site in Barrow, Alaska, and the Tropical Western Pacific site in Nauru) along with dedicated NPOESS overpass radiosondes to measure the temperature and water vapor profiles for validation of the CrIS retrievals. Temporally continuous profiling at the ARM sites will be used to assess small scale spatial variability. GOES, surface networks, and the relative variability of the single-FOV CrIS retrievals will be used to address larger scale spatial gradients. Best estimate profiles and quantitative error estimates will be provided and compared with the coincident CrIS retrieved profiles which have been interpolated in space (using single-FOV CrIS retrievals) to the validation profile locations. AIRS/HSB data will also be used when available.
Scope and Schedule:

The best estimate products produced from the routine ARM observations will be available for validation purposes from the launch of NPOESS onward. During yearly three month long periods, dedicated NPOESS overpass sondes will be launched and incorporated into the best estimate products. During these periods, sondes will be launched every ~90 minutes and ~5 minutes prior to overpass time to provide improved collocation with the satellite overpasses, for the lowest view angle (closest to nadir) overpass of the ARM site each day (e.g. 1 overpass per day, 2 sondes per overpass). Estimates of the number of clear and cloudy overpasses of each site are given in the supporting document.

Comparison and Accuracy:

Rough estimates of the validation profiles show that their accuracies surpass the validation needs of CrIS.

***Supporting Documents*:**

"Position Paper on ARM T/q Best Estimate Profiles for AIRS Validation", D. Tobin et al., March 1, 2000.

Funding: TBD

Approach 2: International Radiosonde Sites

Product:

Moisture, Temperature and Pressure Profiles (integrated column water vapor)

Primary Validation Source:

International Radiosonde sites

Techniques:

The basic approach is to make measurements of temperature and water vapor profiles coincident with CrIS retrievals via overpass coordinated radiosonde launches. Sonde water vapor calibration errors will be addressed by scaling the sonde integrated column water vapor to values measured by a GPS or MWR, or alternatively by scaling to point measurements made with a high quality met station coincident with the sonde measurements just prior to launch. Imager data will be used to assess cloud cover and spatial and temporal variability.

Approach 3: Retrievals from NAST-I and S-HIS aircraft observations at ARM and EOS sites

Product:

Moisture, Temperature and Pressure Profiles (and integrated column water vapor)

Primary Validation Data Source:

NAST-I and S-HIS retrievals

Ancillary Data Sources:

NAST-M, MAS, CLS

Technique:

For high altitude NAST-I and/or S-HIS underflights of the CrIS overpasses, retrievals of atmospheric profiles derived from the NAST-I and/or S-HIS observations will be compared to the CrIS products. Cross-track scanning will allow the aircraft observations to be averaged to match the CrIS footprint. As with radiance validation approaches with S-HIS and NAST-I, the flight paths and sensor scan angles can be tailored to match the CrIS viewing angles. These flights should be performed at maximum aircraft altitude.

A complimentary technique is to perform slow ascents with the aircraft sensors to derive profiles from NAST-I and/or S-HIS data using opaque spectral channels which represent the local temperature and gas concentrations. Such experiments have recently been performed with NAST-I on the Proteus aircraft during the ARM WVIOP 2000 experiment. Due to the slow ascents, these comparisons would be performed on a limited scope for stable, homogeneous meteorological conditions in order to provide meaningful comparisons to the CrIS product.
Funding: TBD

H.1.1.2 Total Precipitable Water (TPW) (EDR)

Approach 1: Comparison to AERONET data
The AERONET network of sun photometers will continue to provide the most viable total precipitable water validation source. AERONET consists of a global network of approximately 100 sunphotometers measuring in several channels in the visible and near-infrared spectrum. The AERONET data can also be used to derive the spectral total column aerosol optical thickness and size distribution.
Funding: TBD

Approach 2: Comparison to EOS products
The comparison plan for the Total Precipitable Water EDR includes sensitivity studies, analysis of VIIRS data, and verification using MODIS products. Observations from MODIS and other space-based sensors will be used in the pre-launch phase to study the error characteristics and optimum techniques for the algorithm. It is expected that MODIS validation data will be of great value. These data are expected to include *in-situ* field measurements combined with MODIS observations. MODIS TPW product will be used in the post-launch era for evaluation purposes of VIIRS TPW EDR at regional and global scales.
Funding: TBD

Approach 3: Comparison to International Radiosondes
The basic approach is to integrate measurements of water vapor profiles coincident with CrIS retrievals via overpass coordinated radiosonde launches. Sonde water vapor calibration errors will be addressed. Imager data will be used to assess cloud cover and spatial and temporal variability.
Funding: TBD

H.1.1.3 Suspended Matter (EDR)

To be included.

H.1.2 Validation Approaches for Aerosol Products

H.1.2.1 Aerosols Optical Depth and Particle Size (EDRs)

Aerosol optical thickness and particle size are primary VIIRS products. Aerosol cal/val, in preparation of using the VIIRS data, is composed of three tasks: 1) to evaluate the self-consistency of VIIRS retrievals of multi-spectral (0.55, 0.66, 0.86, 1.64 µm) aerosol optical depths (AOD), and aerosol particle size parameters (Angstrom Exponent (AE)); 2) to quantify improvement in VIIRS derived AOD and AE relative to those parameters derived from multi-channels of MODIS and two channels of AVHRR and TRMM/VIRS; and 3) to validate VIIRS retrievals of AOD and AE against AERONET sun-photometer measurements.

The overall results from the aerosol cal/val activity (self-consistency checks, inter-satellite comparisons and ground-truth validation) will be used to anticipate and verify the performance of the NPOESS/VIIRS aerosol parameters, and to identify improvements to the VIIRS instrument design and/or retrieval algorithm science.

Approach 1: Comparison to AERONET data
The AERONET network of sun photometers will continue to provide the most viable aerosol validation source. AERONET consists of a global network of sun photometers measuring in several channels in the visible and near-infrared spectrum. The AERONET data can be used to derive the spectral total column aerosol optical thickness and size distribution.
Funding: TBD

Approach 2: Comparison to Lidar data
Surface based lidars at the ARM sites and others provide routine measurements of the profile aerosol backscattering. When other observations can be used to reduce the uncertainty in the backscatter to extinction ratio, lidars can provide accurate estimates of aerosol optical thickness. Dual wavelength lidars also provide profile information on aerosol size. Information on aerosol shape can be derived from the lidar depolarization signal.
Scope and Schedule.
NPP overpasses with AERONET and lidar sites need to be collected.
Comparison and Accuracy
AERONET optical depth measurements can achieve 5% accuracy. Lidar profiles of extinction have a nominal accuracy of 30 % can be improved to 10% with some knowledge of the aerosol type.
Funding: TBD

H.1.3 Validation Approaches for Cloud Products

H.1.3.1 Cloud Base Height / Pressure / Temperature (EDRs)

Cloud base height determinations from VIIRS rely on microwave and ancillary data sources. MODIS offers additional information on cloud base height through its near-infrared water vapor channels (0.94, 1.38 _m). The approach is to develop cloud base height algorithms using MODIS data. Once MODIS-AQUA data is available with the AMSU and HSB microwave instruments, all required inputs to the VIIRS cloud base height algorithm will be available. Then comparison of the methods will be pursued to verify the consistency of the VIIRS algorithm with the MODIS algorithm. In addition, VIIRS does possess one strongly absorbing water vapor channel (1.38 μm). This channel allows estimation of cirrus cloud base height which is one area where the VIIRS algorithm is known to have problems due to the difficulty in detecting cirrus in microwave data. The NPP Cal Val Team will explore ways to include the 1.38 μm channel information to improve the VIIRS cloud base height estimation.

Approach 1: Surface based LIDAR and Ceiliometer Measurements
Validation will be conducted using surface based LIDARS, such as those at the ARM and FARS sites and large networks of ceilometers, providing direct estimate of the cloud base altitude.
Funding: TBD

Approach 2: Cloud Radars measurements
Undermost conditions, cloud radars will be able to provide direct measurement of cloud base. Only for clouds with heavy precipitation, do cloud radars become unable to sense the cloud boundaries. Cloud radars available for NPP validation are those at the ARM and FARS sites and possibly the CloudSat mission. CloudSat will fly with EOS/AQUA and provide validation of the NPP approach using EOS instruments.
Funding: TBD

Approach 3: Comparison with Rawinsondes
Profiles of atmospheric humidity from co-located radiosondes are able to provide information on moist layers which are indicative of cloud positions.
Ancillary Data Sources:
The additional data needed for validation include the products from co-located NWP model outputs, and radiosondes.
Scope and Schedule:
These comparisons can be preformed regularly for NPP overpasses of lidar and ceilometer sites for the duration of the mission.
Comparison and Accuracy:
The lidar, radar and ceiliometer cloud base estimates should be accurate to 100m for most scenarios
Funding: TBD

H.1.3.2 Cloud Cover/Layers Validation (CC/L) (EDR)

Cloud cover and layers are primary VIIRS EDRs, and it can be produced as CDR from CrIS. VIIRS has difficulty sensing overlapping cloud layers. Validation technique described below use active sensors or instruments with high spatial resolution to validate the NPP CC/L estimates.

Approach 1: Comparison with MAS/MODIS and LIDAR data
The VIIRS CC/L algorithm will be validated against MAS data and MODIS data along the imagery track centers where Lidar Cloud Profiling data is available. By inspection, a set of ground truth layered cloud amounts will be determined. These will then be compared to CC/L layered assessments and a qualitative indication of CC/L performance can be

attained. At least one case of MODIS data will be used to validate CC/L algorithm performance. The CC/L product will be validated with independent cloud measurements either from space or other indirect means.

Scope and Schedule:

The Lidar Cloud Profiling measurements of land the SGP and EOS site will be performed once during each season (Spring, Summer, Fall, and Winter). The measurements will be timed to coordinate with any supporting measurements.

Comparison and Accuracy: TBD

Funding: TBD

H.1.3.3 Cloud Effective Particle Size Validation (EDR)

Cloud effective particle is a primary EDR of VIIRS. Information on cloud particle size is also possible from CrIS, ATMS, and CMIS. Cloud effective particle size is defined as the ratio of the third to second moment of the cloud particle radius distribution. The cloud effective particle size varies throughout a cloud layer. Knowledge of the particle size is critical in describing the radiative characteristics of cloud layers. Estimation of liquid water path also critically depends on knowledge of the particle size.

Approach 1: Cloud particle sensing probes flown on aircraft can profile the size distribution of cloud particles through the atmosphere.

Funding: TBD

Approach 2: Cloud particle size profiles can be determined from surface based LIDAR, RADAR and microwave radiometers from the ARM and FARS sites. Similar cloud particle size profiles will be available from the CloudSat mission.

Funding: TBD

Approach 3: Highly calibrated radiometers such as the MAS or AVIRIS that measure radiance in the visible and near-infrared region can be used to derive information on the cloud effective particle size and provide limited information on its profile.

Funding: TBD

Approach 4: Imagers with three or four broad band (spectral resolution around 10 - 20 cm^{-1}) measurements in the infrared window region between 800 to 1000 cm^{-1} are likely to be able to distinguish large from small particle size cirrus and to provide IWP estimates. Cirrus clouds with small ice particles ($r_{eff} < 10$ μm) exhibit a non-linear *S*-shaped cloud forcing in 800 - 1000 cm^{-1} that gradually disappears as the particle size is increased. . A numerical procedure based on the DISORT algorithm is used to retrieve the effective radius and ice water path of cloud layers with known optical depths and cloud boundaries and with nearby clear sky atmospheric conditions also known. The reasonable reproduction in a rather wide window region suggests that the DISORT based algorithm can distinguish small from large particle clouds as well as provide a fair estimate of IWP.

Scope and Schedule: TBD

Comparison and Accuracy:

Ice particle size and ice water paths are estimated with 20% variation in the inferred values. The best sets of effective radius and ice water path can reproduce the observed HIS cloud forcing within 2 K in 800-1000 cm^{-1} and within 4.5 K in 1150-1250 cm^{-1} for both small (r_{eff} < 10 μm) and large (r_{eff} > 10 μm) particle clouds.
Funding: TBD

H.1.3.4 Cloud Optical Thickness (EDR)

Algorithms for estimating cloud optical thickness and effective particle size will be evaluated in terms of their sensitivity to variations in the vertical profile of particle size and to ice particle shape ("habit"). The vertical distribution of particle size in water and ice clouds is rarely uniform, so inhomogeneous cloud structure will affect retrievals of particle size. MODIS/VIIRS bands at 1.6, 2.1, and 3.75 _m can be used to provide additional information about the vertical structure of particle size because they are sensitive to different portions of the cloud, depending on the particle density. Ice particle shape will also effect retrievals of the bulk micro-physical properties, as different shapes exhibit different optical properties. A parameterization of ice cloud optical properties for various particle habits has been recently developed, so the tools are in place for this task. The NPP Cal Val Team is interested in the performance of the algorithms under extreme conditions, specifically for very small ice particles, mixed-phase clouds, and bright, anisotropically reflecting surfaces found in the Polar Regions. Lastly, Numerical Weather Prediction (NWP) impact studies regarding the assimilation of satellite-derived cloud properties will be initiated.

Approach 1: Cloud Optical Thickness can be derived from the profile of cloud liquid and ice water contents and particle size distributions measured from probes mounted on aircraft. Optical depth can also be derived from highly calibrated airborne sensors such as AVIRIS.
Funding: TBD

Approach 2: Surface based RADAR, LIDAR and microwave radiometers such as those at the ARM and FARS sites also provide estimate of cloud optical and its vertical profile.
Funding: TBD

Approach 3: Satellite based RADAR and LIDAR missions such as CloudSat and ESSP-3 will provide independent measurements of cloud optical thickness.
Ancillary Data Sources:
Data for NPP overpasses will need to be collected as well as estimates of atmospheric temperature and moisture profiles.
Scope and Schedule: **TBD**
Comparison and Accuracy: Expected accuracy of aircraft derived optical depth is 5%. The RADAR and LIDAR estimates of optical depth are typically 10 % for water clouds and 30 % for ice clouds.
Supporting Documents:
Funding: TBD

H.1.3.5 Cloud Top Height / Pressure / Temperature (EDRs)

The proposed VIIRS algorithm for cloud top pressure relies on radiances at 0.67, 3.7 and 10.8 microns to retrieve cloud top properties including cloud top pressure. The CrIS algorithm employs the CO2 slicing technique. The VIIRS channels do not allow for CO2 slicing but the NPP Cal Val Team will study supplementing the VIIRS with CrIS measurements observations. Algorithms for estimating cloud top pressure will be evaluated in terms of their sensitivity to variations in the cloud vertical profile, particularly for optically thin clouds. The performance in Polar regions and regions with non-black surfaces must also be evaluated.

Approach 1: CO2 slicing comparisons
Cloud top pressure will be estimated using the CO_2-slicing approach with high spectral resolution sounder (e.g., CrIS , AIRS , IASI or HIS) radiances and/or co-located high spatial resolution multi-spectral imaging radiances (e.g., MODIS). These algorithms retrieve the single layer atmospheric CTP and ECA from a single field-of-view (FOV) with higher accuracy than the current operational sounders (HIRS).
Funding: TBD

Approach 2: Satellite, aircraft and surface based LIDAR and RADAR product
LIDARs and RADARS provide direct estimates of the cloud top altitude. For example, the ARM site ARSCL product can validate both the CrIS and VIIRS cloud top heights. ARSCL combines the MPL and MMCR measurements into a single product of cloud layers (base, top, thickness) versus time at each of the primary ARM sites. Similar approaches will be used to compare the CloudSat and other aircraft based RADAR and LIDAR estimates of cloud top height to those from VIIRS/CrIS.
Funding: TBD

Approach 3: Geometric stereo determinations
Estimation of cloud top height are possible from LEO/GEO high spatial resolution imagers viewing the same cloud at the same time from different view angles
Ancillary Data Sources: The additional data needed for validation include the products from co-located Vaisala ceiliometer, winds from Wind Profilers, NWP model outputs, and radiosondes.
Scope and Schedule: These comparisons can be preformed regularly for NPP overpasses of each ARM site and the FARS sites for the duration of the mission.
Comparison and Accuracy: For single layer clouds with optical depths <=1, the ARSCL product is expected to be accurate to better than ~100m. For CO2 slicing validation estimates, cloud pressure will be determined within 30 hPa.
Funding: TBD

H.1.4 Validation Approaches for Land Products

H.1.4.1 Land Surface Temperature (LST) (EDR)

An accurate measure of the LST is essential to initialize, validate and verify climate models designed to assess the role of the land surface in governing seasonal-to-interannual variability at regional-to-global scales. The ability to monitor the land-surface energy flux will improve the understanding of the land-atmosphere climate interactions.

The surface emissivity is a physical property that relates the emitted radiance to the surface temperature – analogous to a radiative efficiency. Knowledge of the emissivity of land surface components is necessary for accurate determination of land surface temperatures. The emissivity of healthy vegetation is predictably high in the TIR (and may be assumed with relatively small error to be approximately 0.98), the emissivity of bare ground is another matter.
The variation of emissivity of soils is dependent on constituents, surface texture and moisture content. The TIR emissivity has also been observed to be directional dependent for some soil surfaces.

Validation approaches should include a large range of surface emissivities, and determine the performance of the LST algorithm over a various environmental conditions.

Approach 1: Comparison to ground and aircraft observations
The validation data set is expected to include *in-situ* field measurements using S-AERI instrument at ARM sites, and using over top radiometers at EOS sites, combined with MAS and NAST-I underflights, and low level aircraft measurements at spatial resolutions less than 10 meters. MODIS and ASTER are planning multiple field validations using AERI instruments, and VIIRS will find beneficial cost saving in collaborating in these future activities. VIIRS LST EDR products will be compared with “truth” derived from *in-situ* and aircraft data, and performance characteristics will be provided.
Funding: TBD

Approach 2: Comparison to EOS products
The comparison plan for the Land Surface Temperature (LST) EDR includes sensitivity studies, analysis of VIIRS data, and verification using MODIS products. Observations from MODIS, ASTER and GLI will be used in the pre-launch phase to study the error characteristics and optimum techniques for the algorithm. It is expected that MODIS validation data will be of great value. This data is expected to include in-situ field measurements combined with MODIS observations. MODIS LST product will be used in the post-launch era for evaluation purposes of VIIRS LST data at regional and global scales.
Funding: TBD

H.1.4.2 Albedo (Surface) (EDR)

Approach 1: Pyranometers and albedometers data
Product:
Surface Albedo
Primary Validation Data Source:

Albedo is defined as the ratio of surface exitance to surface irradiance, both measured over the full shortwave spectrum. These quantities are measured with pyranometers (two required: one facing up, the other down). Some vendors package the pyranometers in a single unit, called an albedometer. The pyranometers are typically mounted on towers at heights well above the vegetation height, or on aircraft.

Ancillary Data Sources:

Several observation networks, composed of multiple ground sites hosting standard instrumentation packages, measure albedo routinely. These include SurfRad, BSRN and FLUXNET. The latter includes forested sites, while the SurfRad and BSRN commonly include primarily desert and grassland locations. These data can typically be downloaded from the internet, though the networks and archives tend to be voluntarily maintained and inconsistently funded. Global albedo data sets have been derived from other satellite systems, including AVHRR (Los et al., xxx) and EOS MODIS (ref?). Both are widely available, however their accuracies are not well known. Coarser scale albedo data are available from EOS CERES, ADEOS POLDER (< 1 year) and METEOSAT (regional only). The EOS MISR team produces accurate but temporally and spatially inconsistent albedo products. A second POLDER instrument is awaiting launch on ADEOS II. Some of these products are top-of-canopy, while others are top-of-atmosphere.

Technique:

The key problem in validating albedo concerns temporal vs. spatial resolution. A tower-based albedometer generates highly accurate data at very high temporal resolution at minimal cost, however that albedometer's spatial field of view is limited by its relatively short distance above the vegetation, and its fixed position. These point data can be scaled to approximate larger area albedo fields, however scaling techniques are not well developed at this time. To sample much larger areas, some scientists have mounted albedometers on aircraft. This approach appears promising (at least one instrument vendor recently developed a pyranometer with appropriate thermal stability for aircraft use), however it is expensive, and data may need to be corrected for atmospheric effects (depending on aircraft altitude), geolocation, and aircraft attitude. Standard processing packages do not exist to our knowledge. Because albedometers essentially measure a quantity equivalent to the albedo EDR product (assuming appropriate spatial scaling), comparison of in-situ data to EDR values is straightforward. Advancement of albedo measurement and scaling approaches will presumably result from the EOS validation program.

Scope and Schedule:

Because albedo is a key parameter in any energy budget calculation, the EDR and its validation are critical. Validation of this parameter should be a priority after launch, and correlative data from all major ecosystems should be acquired for the duration of the mission. At least some global analysis should be possible within several months of initial product generation. Albedo varies at high frequency, both temporally and spatially. A large wind gust or rainfall event can immediately change a surface's albedo, and the "recovery" time to near stable conditions varies greatly. Thus, data averaging is essential, although there are no established standards.

Comparison and Accuracy:

Field measurements of albedo are accurate to the uncertainty of the instrument's calibration, typically about 1 %. Scaling point albedo measurements to larger areas (commensurate with the EDR pixel size) introduces additional errors that vary with the aggregation method.

Supporting Documents:

MODIS and VIIRS ATBDs.

Funding: TBD

H.1.4.3 Surface Type Validation (EDR)

Approach 1: Comparison to EOS-derived surface type maps

Primary Validation Data Source:

MODIS, Landsat-7, Ikonos, field survey

Ancillary Data Sources:

Training data set over a year at well distributes sites.

Technique:

Using climatic and geographic stratification, the accuracy will be determined for VIIRS surface type. The validation will performed using high and fine resolution remote sensing data such as Landsat-7 data and Ikonos data. Ground field survey and airborne data might also be used when necessary.

Scope and Schedule:

Surface type maps at elected ARM and EOS [TBD] data will be derived for 4 seasons using fine-, high- and moderate resolution.

Comparison and Accuracy:

The analysis to be performed at these selected site is based on the comparison between VIIRS product, MODIS and other commonly used land cover maps (USGS and UMD land cover maps) over one year and for 4 seasons.

The analysis will include percent error for each class and percent of estimating and underestimating each class globally and regionnally.

Supporting Documents:

VIIRS ATBD, MODIS ATBD

Funding: TBD

H.1.4.4 Vegetation Index Validation (EDR)

Approach 1: MODIS and POES comparisons

The visible and near-IR channels included on the MODIS instrument permit evaluation of narrower (and atmospherically clean) wavebands for use in vegetation indices that might be anticipated to be available from the VIIRS. This study will examine the influence of the use of narrow band visible and near-IR channels on vegetation indices anticipated to be available from the VIIRS. The VIIRS vegetation EDRs will be compared to those available from the present AVHRR. Differences in the vegetation indices will be assessed for several vegetated land surface types (IGBP classification). This study should result in i) assessment of the anticipated improvements in vegetation index products from the VIIRS and ii) general guidelines for comparisons of VIIRS-derived vegetation indices, when available, with historical AVHRR-derived vegetation indices. VIIRS EDR data sets for several extended periods will be generated through an annual cycle for the whole globe, and inter-comparison will be performed with MODIS products.

Comparison and Accuracy:
Supporting Documents:
VIIRS Vegetation Index ATBD
Funding: TBD

Approach 2: Ground and aircraft data
Primary Validation Data Source:
Spectrometer, Parabola, MQUALS, MAS
Ancillary Data Sources:
Atmospheric data
Technique:
The airborne data from MQUALS instrument over representative biome types (i.e. desert, grasses/cereal crops, broadleaf crops, shrub land/savanna, needleleaf forests, broadleaf forests) will be acquired during the validation period. The flights will be conducted on days in which VIIRS will scan the targets at a near-nadir position. Except for an AERONET sunphotometer (to assess atmospheric aerosols) and a stable reference plate (irradiance). These rapid but low cost assessments will satisfy three goals:

1) They will provide feedback on different Level 1B processing chains and their potential effects on land products,
2) they will provide early quantitative checks on two critical "upstream" land products (atmospheric correction, surface reflectance, vegetation index, and albedo), and
3) they will provide high spatial resolution surface heterogeneity data for more accurate scaling at validation test sites.

The spatial variability of reflectance and albedo observed by MQUALS at the selected validation sites will allow the construction of a spatial model of reflectance and albedo based on TM-derived spatial patterns. This will link the data stream generated at the core site with the coarser spatial resolution of VIIRS land products. Longer transects to be flown by MQUALS across landscape gradients will allow investigation of transitions in land cover type and the properties of NDVI and reflectance products across a surface area to be determined. Initial results are anticipated within 1-2 weeks of VIIRS data delivery.
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding: TBD

H.1.4.5 Fire Area and Temperature Validation (EDR)

Approach 1: Comparison to EOS fire product
Statistical relationships will be established between AVHRR, MODIS and VIIRS-derived fire numbers over specific areas and time periods. Results of this study will be useful for the construction of a continuous AVHRR-MODIS-VIIRS data record of fire occurrences for long-term studies. VIIRS products will be evaluated for their physical limits, precision, and accuracy, using theoretical calculations and ground observations wherever available. These results will be compared with the VIIRS EDR requirements and recommendations will be made regarding VIIRS fire algorithm design. Potential for MODIS-VIIRS product

stitching will be evaluated. Finally, it is also proposed to perform feasibility studies towards a time-integrated burned area product from VIIRS. This product eliminates most of the active fire misses due to clouds and low temporal resolution and thus is much more suitable for emission estimates and hazard assessment. Changes in the signal of near-IR channels from healthy vegetation to post-burning conditions will be studied and recommendations will be made for an operational algorithm.

Scope and Schedule:

Comparison and Accuracy:

Supporting Documents:

MODIS fire ATBD

Funding: TBD

H.1.4.6 Soil Moisture (EDR)

Approach 1: Validation using SGP ground measurements

Primary Validation Data Source:

Southern Great Plain (SGP) experiment data

***Ancillary Data Sources*:**

Soil type data, Digital Elevation Model data

Technique:

Validation of soil moisture estimation results is difficult and even more so if satellite data is involved. The difficulty lies not only in the estimation process but also in the measurements of soil moisture. Several issues are involved in soil moisture measurements. Microwave sensors measure soil moisture in the topmost soil layer (1/10 to 1/4 of a wavelength). At 19 GHz, this layer can be about 0.1-0.4 cm deep. The penetration of the microwave signal depends on soil moisture itself. In view of this, it is difficult to decide the depth of soil samples for in-situ measurements. Soil moisture changes very rapidly in the top layer. In addition, there are practical problems in collecting soil samples at this depth. Also, spatial distribution of soil moisture depends on soil parameters, which are not distributed homogeneously in the area. As a result, average soil moisture computed from point measurements in a footprint area may not be a correct representation of the soil moisture in the footprint.

Close comparison of *in-situ* measurements from SGP experiments with the VIIRS soil moisture predictions will be attempted, as well as the temporal and spatial comparisons.

Scope and Schedule:

Data acquisition of a large range of soil moisture will be conducted coincident with cloud-free VIIRS data. Coordination with other field campaigns is required.

Comparison and Accuracy:

VIIRS Temporal and spatial pattern/trend in soil moisture at the selected sites will be compared from all averaged samples for a particular location on a given day.

Supporting Documents:

Soil moisture ATBD

Funding: TBD

H.1.5 Validation Approaches for Ocean Products

H.1.5.1 Sea Surface Temperature (SST) (Primary EDR)

The measured SST is the temperature of the surface skin of the water surface, that temperature that gives rise to the infrared emission that is detected by the VIIRS and CrIS. At the level of accuracy of a few tenths of a degree, anticipated for NPP sensors, the remotely sensed skin temperature is distinct from the *in situ* measured subsurface (upper 1 meter) bulk temperature. The EDR requirements are given for skin and bulk SST in Appendix B, Table 22 derived from the NPOESS Integrated Operational Requirements Document [IORD] and the NPOESS Technical Requirements Document [TRD]. Both the skin and bulk SST EDR products will be generated from the NPP data. Both the bulk and the skin SSTs will be validated.

The bulk SST has been used operationally and has gotten wide use in numerical weather modeling. Both NPP SST EDRs are expected to be widely utilized for ocean, climate, and NWP purposes. National and International collaboration with other projects will have high priority.

Approach 1: Marine-Atmospheric Emitted Radiance Interferometer (M-AERI) Comparisons

Ancillary Data Sources:

Atmospheric characterization at the time of the comparisons, using instruments on the ships and NWP data assimilation model output.
Aerosol characterization from NPP/NPOESS and from sensors on other spacecraft.
GOES SST product for temporal stability from NOAA.

Techniques:

VIIRS and CrIS SSTs are extracted along M-AERI cruise tracks within a predefined time and spatial intervals. Co-location must be within a few km, and within a few tens of minutes. Cloud-free and reasonably uniform and temporally stable targets will be selected with a range of radiance levels encompassing the range of surface temperatures observed by M-AERI and atmospheric water column amounts measured by CrIS

Scope and Schedule:

All ocean basins must be covered, and atmospheric variability as well as the full range of SST should be sampled. The validation should begin soon after launch and continue throughout the mission.

Comparison and Accuracy:

The comparison of VIIRS and CrIS SST and M-AERI SST products is simplified by the high absolute accuracy of the M-AERI (< 0.1 K) but complicated by the large mismatch between the CrIS SST domain (order 45 km) and the M-AERI measurements along the ships' tracks. A major source of uncertainty in the SST product comparison is expected to be the spatial variability within the CrIS and VIIRS scene. Uncertainty estimates will be developed to allow error bars to be attributed to each, VIIRS, CrIS, and M-AERI comparison. The goal of this activity will be to validate the CrIS and VIIRS SST product to within about 0.1 Kelvin over as wide range of atmospheric conditions as possible.

Funding:

The M-AERIs cost about $250,000 each and over the period of the NPP and NPOESS validation they will need significant refurbishment, possibly replacement. Funding is required for the sea-going technicians, and for the shore based facilities that are used to maintain and calibrate the equipment. IPO, NOAA, NASA and DOD contributions will likely be required.

Approach 2: Shipboard radiometer comparisons.
Well-calibrated infrared radiometers, such as CIRIMS, ISAR, SISTeR, DAR011 and the JPL Nullling Radiometers can provide measurements of skin SST for VIIRS and CrIS validation. These, and others, are mounted on ships. They require internal calibration, traceable to national standard thermometers, and must include a correction for sky radiance reflected at the sea surface. Each radiometer should be accompanied by a suite of auxiliary sensors to characterize the environment in which the measurements are taken, such as cloud influences, aerosol effects, atmospheric water vapor loading, surface wind speed, near-surface wind speed and air sea temperature difference.

Approach 3: Satellite Radiometer Comparisons
VIIRS and CrIS SSTs may be validated by comparison with satellite-derived SSTs from similar imaging radiometers, such as MODIS, AATSR, GLI and AVHRR that may have a longer and more-established calibration/validation history. If these radiometers have similar spectral responses in the corresponding channels, and are on satellites in orbits close to that of NPP, it may be possible to cross-validate top-of-atmosphere brightness temperatures. Inter-satellite comparison can be done over large areas of cloud-free ocean.
Funding: TBD

Approach 4: Validation using sensors mounted on ships and buoys
This has been the first and primary approach for operational uses. In this approach in-situ thermometers mounted at a depth of one to several meters on drifting and moored buoys provide a sub-surface measurement, conventionally referred to as bulk temperature Similarly, thermometers mounted on the hulls and in the engine cooling water intake flow of selected ships can be used if carefully calibrated. At wind speeds greater than ~6m/s, the relationship between skin and bulk temperatures appears to be fairly well constrained, so these data should be restricted to these conditions or during the night. During the day in conditions of lower wind speed, vertical temperature gradients can decouple the bulk measurement from the skin temperature. These factors will be considered in the validation of both the skin and the bulk SSTs.
Funding: TBD

Approach 5: Retrievals from MAS and NAST-I low altitude aircraft measurements
Low altitude flights of the Proteus and/or ER-2beneath the NPP will be conducted with the NAST-I and MAS. Micro-windows will allow for determination of the SST under minimal atmospheric attenuation conditions.
Funding: TBD

Approach 6: GIFTS Observations
The GIFTS in geostationary orbit and with very high spatial and spectral resolution will enable measurements of SST coincident with underpasses of the NPP.
Funding: TBD

H.1.5.2 Ocean Color and Chlorophyll Validation (EDR)

Retrieval of normalized water leaving radiances for the ocean visible and near-IR bands from TOA radiances involves correction for numerous atmospheric effects and reflection of sky and sun light from the air-sea interface, as well a removal of small, but crucial instrument biases and effects. The initialization phase discussed under Level 1 validation using primarily data from the MOBY buoy and ship based measurements of in-water radiances and above water reflectances produces a consistent retrieval system comprised of the instrument data and atmospheric correction algorithm. This is discussed in detail in the MODIS ATBD for water-leaving radiances by Gordon. The resulting water-leaving radiances for the visible bands provide the basis for all other ocean color (ocean bio-optical) properties, including chlorophyll a and suspended sediment load. Therefore the careful validation of this SDR is crucial to ocean color products.

Approach 1: MOBY Comparisons
Primary Validation Source:
Marine Optical Spectrometer (MOS) instruments on MOBY or ship.
Ancillary Data Sources:
VIIRS data, nLw from heritage sensors on orbit, or historical
MOBY servicing cruise data, MOBY calibration/characterization data
Techniques:
Automated collection of MOBY data at the time of VIIRS overpasses, and MOS data during MOBY servicing cruises within the swath, and development of a matchup data base to sample the useful range of VIIRS swath and sun angles. The overall approach for MOBY is discussed by Clark and Mueller in Chapter 11 of the Revised SeaWiFS Protocols for Calibration/Validation. Multiple radiometer buoys are maintained, and are deployed sequentially for three month intervals. Refurbishment and recalibration is done on shore. Optical collectors are cleaned monthly, and in-water calibration stability sources are employed before and after by divers. The measured spectral response function of the satellite sensor is convolved with the high resolution spectrometer data. Upwelled spectral radiances are collected at 3 depths and propagated to and through the surface to produce the desired water-leaving radiance values which are compared with the values retrieved from the satellite sensor.
Scope and Schedule:
The MOBY facility, located on Oahu and off Lanai, must be maintained continuously throughout the mission, and will provide daily observations. Useful matchups will be obtained for only a fraction of the days due to cloud obscuration and solar/scan geometry.
Comparison and Accuracy:
Through concentrated effort, including active participation of NIST personnel and facilities, the uncertainty of the MOBY water-leaving radiance time series is on order of 3%.
Funding:
Currently MOBY is funded via EOS (80%), SeaWiFS (10%), and NESDIS (10%) with annual total ~2M$/yr. Continued funding by EOS will likely decrease over the next few

years, even with a planned shift from MODIS science team to EOS Project Validation Facility (analogous to AERONET). It is crucial that resources be identified to continue this national facility. IPO, NOAA, DOD contributions will likely be required.
Accuracy Requirements:
The goals for these measurements are an overall accuracy in an absolute sense of 2%, with a relative spectral (band-band) of 0.5%, over the time series.

Approach 2: Other In-water radiance measurements
A variety of instrumentation and protocols to make individual and time series of water-leaving radiance and also above water reflectance measurements from ship, moorings, drifting buoys, and permanent platforms have been developed. Details can be found at the SIMBIOS web site. These measurements, most by independent investigators, are very important for validation of the global water leaving radiance signals following initialization at the MOBY site. An extensive round robin comparison and inter-calibration network has been established, led by the SIMBIOS Project at GSFC and with participation by NIST, including US and many international programs. Included in this network are permanent locations on oceanic research towers and moorings. Absolute and relative uncertainty goals are as for MOBY. These are maintained through intercomparison activities, and use of portable stability sources during cruises and field programs.
The SIMBIOS paradigm is that each ocean color flight project will mount a focused calibration validation program, with SIMBIOS serving as an inter-mission comparison facility, maintaining protocols, data bases for global intercomparisons, and center of expertise.
Funding: TBD

Approach 3: Validation using aircraft sensors
Use of aircraft sensors for validation of water-leaving radiances is primarily in the area of providing improved spatial variations and coverage. Maintaining sufficiently accurate absolute uncertainty of the instrument and its atmospheric correction for use in direct validation of water leaving radiance has improved significantly over the past decade, however. Aircraft sensors show great utility in validation of bio-optical properties, but cannot provide the high degree of accuracy of in-water or shipboard observations at this time.
Funding: TBD

H.1.5.3 Ocean Chlorophyll Validation (EDR)

Calculation of chlorophyll concentration is from normalized water leaving spectral radiances at the pixel level. Major sources of uncertainty involve the uncertainty of the water leaving spectral radiance, and the complexity of the optical absorption and scattering properties of the marine hydrosol. Current in-water bio-optical models work best when phytoplankton dominate the optical properties (Case I) which comprise about 90% of the global oceans, and further assume a relatively constant and uniform species composition. Departure from these conditions can result in significant errors. These errors can be due to increased influence of bottom reflectance, presence of suspended sediments, absorption by non-phytoplanktonic particulate matter, departures from 'nominal' absorption and scattering of phytoplankton due to biological variability, and absorption by dissolved. The goals of the measurement are to determine chlorophyll accuracy to within 30% in Case I waters, and 50% in other regions. (check this for consistency)

Approach 1: In-water measurements

Techniques:

The primary approach for validation of chlorophyll concentration is filtration of a water sample followed by High Performance Liquid Chromatography (HPLC) using recognized standards. Determination by fluorescence, both in-vivo and in vitro is also routine, the former especially for underway measurements from ships and from buoy instruments. It is also important that other bio-optical properties of the water be determined at the same time, in order to assess the nature and quality of the overall measurement. Procedures are covered in the SeaWiFS Protocols documents, which cover the need to spatial variability and determination of the accuracy and precision of the measurements. One needs to distinguish between an algorithm validation activity, and a product validation activity. Algorithm validation tends to be more robust, and relies upon relating estimates of water leaving radiance (or reflectance) obtained on shipboard simultaneously with in water measurements of chlorophyll (or other bio-optical property as appropriate). The number of values for such comparisons for doing this is large and covers many conditions and is contained in various data bases. Those data are used to parameterize the algorithm used to derive chlorophyll from satellite derived water-leaving radiance values. This work will continue. Validation of the NPP data product encompasses the total error budget for the values given in the product. The product validation reveals regional and temporal differences, includes uncertainties within the satellite calibration and data processing, and spatial and temporal sampling issues. Generally comparisons are done using data collected within hours and at the pixel or averaged over a few pixels. Consideration also needs to be given to direct comparisons of weekly averaged in-situ and satellite data.

Scope and Schedule:

These measurements should be global in extent, and should address the geographic and temporal/spatial variability in that is found in the marine environments. Development of a data base of matched VIIRS and in-situ data is essential, and the SeaBASS system developed by SeaWiFS and also used for EOS would serve as a good model for the operational system. These efforts are primarily at a local level, and should begin shortly after the VIIRS begins visible data collection.

Accuracy Requirements:

The goals for these measurements are an overall accuracy in an absolute sense of 2%, with a relative spectral (band-band) of 0.5%, over the time series.

Funding:

There should be a dedicated VIIRS component for leading this effort, performing the matchups and the comparisons. Collection of the data is best approached through a combination of operational data collection by NOAA and USN, and collection of data by scientific researcher funded separately by the three agencies and others (NSF, DOE, EPA, and state and local management agencies for coastal regions). Great potential exists for international participation through joint and reciprocal activities with ESA and NASDA.

Some of these are coordinated through the International Ocean Color Coordinating Group (IOCCG), which is organized under CEOS and IGBP.

Approach 2: Comparisons with other satellite sensors
Comparison with concurrent and heritage satellite derive chlorophyll concentrations is extremely valuable due to the very sparse global distribution of in-water measurements. The goal of this comparison is to first define inconsistencies and differences between sensor products, both of which are subject to uncertainty. Such comparisons can identify sources of uncertainty relating to spectral band characteristics, observation time of day, in-water BRDF, and particular atmospheric correction implementations. In this regard, data from sensors using a similar approach as VIIRS are given higher priority, such as SeaWiFS and MODIS and GLI, in contrast to POLDER.
Funding: TBD

Approach 3: Validation using aircraft sensors
Several aircraft sensors are very useful for validation of derived chlorophyll concentration over regional areas. These include the Airborne Oceanographic Lidar and the Satlantic Airborne Simulator.
Funding: TBD

H.1.5.4 Net Heat Flux (EDR)

To be included.

H.1.6 Validation Approaches for Snow and Ice

H.1.6.1 Fresh water Ice edge Motion (EDR)

Approach 1: Comparison using EOS data
Primary Validation Data Source:
AVIRIS, MAS and MODIS
Ancillary Data Sources:
Technique:
The comparison plan for the Sea Ice Age and Sea Ice Edge Motion EDR includes sensitivity studies, analysis of VIIRS data, and verification using MODIS products. Observations from AVIRIS, MAS, MODIS, GLI will be used in the pre-launch phase to study the error characteristics and optimum techniques for the algorithm. It is expected that MODIS validation data will be of great value. This data is expected to include in-situ field measurements combined with MODIS observations, MAS underflights, and low level aircraft measurements at spatial resolutions less than 10 meters. VIIRS data are used to produce Sea Ice Age/Edge Motion EDR products, and compare these results with “truth” derived from in-situ, aircraft, and MAS data. The potential for VIIRS/CMIS data fusion to produce First Year/Multi-year classification and ice edge motion will be studied with the use of MODIS data and Advanced Microwave Scanning Radiometer (AMSR) data.
Scope and Schedule:
Comparison and Accuracy:

Supporting Documents:
Sea Ice Age/ Edge Motion ATBD
Funding: TBD

H.1.6.2 Ice Surface Temperature (EDR)

Approach 1: Comparison to EOS products
The Government Team will evaluate ice surface temperature data from MODIS with respect to current operational and experimental NWS and NESDIS products, such as those from AVHRR/3. The purpose is to reduce the risk associated with the use of NPOESS/VIIRS products in NESDIS and NWS operations. The benefit of incorporating the additional spectral information available with MODIS in ice surface temperature retrieval procedures will be evaluated, as will the use of new field data. Co-located AVHRR, MODIS and VIIRS images and derived products will be compared from local to hemispheric spatial scales for accuracy and quality. For example, IST products over a variety of North American watersheds, North America and Eurasia, the Northern Hemisphere, arctic and antarctic will be evaluated. Samples of derived products will be made available to NCEP, the National Ice Center, and the scientific community for evaluation. This evaluation process will provide feedback that may lead to modification of the VIIRS algorithms.
Scope and Schedule:
Comparison and Accuracy:
Supporting Documents:
Funding: TBD

Approach 2. In-situ and Airborne Instrument Comparison
In-situ and airborne data will be used in the validation. These data will come primarily from NWS meteorological stations and NPP cal/val sites. Reports detailing the methods and results of the evaluation, and recommendations for NPOESS VIIRS proposed designs will be proposed.
Funding: TBD

H.1.6.3 Snow Cover and Depth (EDR)

Approach 1. MODIS and POES Comparison
The Government Team will evaluate a combination of Levels 1, 2, and 3 snow and ice data, imagery, and derived products from MODIS with respect to current operational and experimental NWS and NESDIS products, such as those from AVHRR/3. The purpose is to reduce the risk associated with the use of NPOESS/VIIRS products in NESDIS and NWS operations. The NWS National Operational Hydrologic Remote Sensing Center (NOHRSC) will obtain the MODIS products via the Internet from the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin. The NESDIS/ORA will obtain the MODIS products through the NESDIS provided server at NASA/GSFC. The benefit of incorporating the additional spectral information available with MODIS in ice surface temperature retrieval procedures will be evaluated, as will the use of new field data and improved model in the retrieval of snow albedo from satellite.

MODIS and VIIRS snow and ice mapping products are very similar. MODIS imagery and derived products for snow cover, snow albedo, snow/cloud discrimination, sea ice cover, ice surface temperature, ice/cloud discrimination, and lake ice will be evaluated relative to existing NWS and NESDIS products. Personnel from NOHRSC, CMISS, and ORA, as well as operational meteorologists from NESDIS/OSDPD, and the National Ice Center will perform the evaluation. Co-located AVHRR and MODIS images and derived products will be compared from local to hemispheric spatial scales for accuracy and quality. For example, NOHRSC will evaluate imagery and products over a variety of North American watersheds, ORA will focus its investigation on the regions of North America and Eurasia, and the Northern Hemisphere, and CIMSS will investigate ice surface temperature and albedo in the arctic and antarctic regions. Samples of derived products for snow cover and depth, surface albedo, sea ice age/edge motion, ice surface temperature, and fresh water ice, and cloud cover/layers will be made available to NCEP, the National Ice Center, and the scientific community for evaluation. This evaluation process will provide feedback that may lead to modification of the VIIRS algorithms VIIRS design.

Approach 2. In-situ and Airborne Instrument Comparison
In-situ and airborne data will be used in the validation. These data will come primarily from NWS meteorological stations and DOE ARM CART sites. Reports detailing the methods and results of the evaluation, and recommendations for NPOESS VIIRS proposed designs will be produced by NOHRSC, CMISS, and ORA. This study will also allow NOHRSC to determine the usefulness of a VIIRS-MODIS ground receiver.
Funding: TBD

H.2 Validation Approaches of the CDR Climate Research Products

H.2.1 Atmospheric Sounding Profiles Validation

H.2.1.1 Clear Column Radiance (CDR)

Validation approaches proposed for the Clear Column Radiance CDR is the same as the ones proposed for the CrIS radiance validation described in section H.1.1.1

H.2.1.2 CrIMSS Precipitation Rate (CDR)

Instantaneous precipitation rate (mm/h) is desired for operational, research, and climatological purposes. Cloud Precipitation Rate is that instantaneous precipitation-rate estimate achievable using CrIMSS that produces on a global scale the best achievable equivalent to NEXRAD-based estimates. To the extent that CrIMSS may prove to be more sensitive to snowfall or light rain, CPR will deviate from NEXRAD results to take advantage of these characteristics. That CrIMSS can provide useful CNTPR estimates has been demonstrated (Staelin et al., 2000; Chen and Staelin, 2001).

Approach 1: Comparison to NEXRAD data
By definition of CPR, the prime validation source must be coincident NEXRAD data (offsets < 5 minutes), with emphasis on the eastern United States because of NEXRAD's

more complete coverage there. The NEXRAD data must be convolved with a response function characterizing the appropriate 15- or 50-km antenna pattern. Radars operating at other frequencies and global locations will provide secondary validation. Snow pillows can provide more accurate ground truth for snowfall retrievals (water-equivalent mm/h).
Supporting Document:
D. H. Staelin and F. W. Chen, “Precipitation observations near 54 and 183 GHz using the NOAA-15 satellite,” *IEEE Trans. Geosci. and Remote Sensing, 38*, 5, 2000, pp2322-2332; and F. W. Chen and D. H. Staelin, *IEEE Trans. Geosci. and Remote Sensing*, 2002, in press.)
Funding: TBD

Approach 2: Comparison to BALTRAD data
BALTRAD radar data available for the Baltic region will be used in conjunction with Snow/Ice cover maps to derive precipitation data. Radar data will be convolved to the spatial resolution and observation geometry of the ATMS. Probability of detection as a function of the precipitation intensity will be derived. The precipitation screening algorithms will be adjusted according to findings.
Funding: TBD

H.2.1.3 Ozone validation (CDR)

A likely candidate for a CrIS/ATMS CDR is the total column ozone and the vertical ozone profile. Although ozone will be measured on NPOESS/OMPS it is desirable to produce an ozone product in the NPP timeframe in order to extend the ozone record that will be available from AIRS. The ozone vertical structure in the troposphere will be indicative of the oxidizing potential of the lower atmosphere, and the stratospheric profile is needed for data assimilation and studies of stratospheric ozone recovery.

The total column ozone should be retrieved at a resolution of .03 atm-cm, with an accuracy better than 10%.

Approach 1: Comparison to EOS and other program products
Currently, the available satellite instruments producing ozone products include TOMS, SAGE-II, SBUV-2, HALOE, and MLS. After NPP launch, in addition to CrIS/ATMS, AIRS and SAGE-III will also be producing ozone products. One of the advantages of satellite based calibration is the availability of a large number of observations at periodic time intervals. The lifetime of the AIRS instrument on the Aqua platform is expected to overlap with that of NPP. AIRS will be producing similar ozone products on a global scale that will continue after NPP launch. This makes it a perfect candidate for cross-instrument calibration. Except for differences in the temporal and geographic position of the retrieved profiles, that need to be accounted for, the ozone products from AIRS and CrIS/ATMS are readily comparable and can be used for calibration of CrIS/ATMS. Longer-term trends and instrument degradations can also be determined using AIRS data. Total column measurement of ozone is currently measured from space through the TOMS series of instruments (EP-TOMS currently on the Earth Probe satellite and on the QuikTOMS platform). An indirect measure of the tropospheric column is possible by subtracting an

integrated stratospheric profile from SAGE-III, from a total column. These calibration methods will be of less importance with the successful operation of AIRS.
Funding: TBD

Approach 2: Comparison to In-situ data
Ozonesondes have been a standard instrument for measuring ozone from the ground to the lower stratosphere. A long-term measurement database exists (as long as 35 years for some sites), mostly within the Northern Hemisphere mid-latitudes, on a roughly once-a-week basis. Ozonesondes measurements offer good precision and excellent vertical resolution (about 150 m), although results become more uncertain above 25 km because of inefficiencies in pumping mechanisms, and corrections may be needed to SO_2 interference. For NPP, the major difficulties are the comparatively low geographical and temporal density of ozonesonde measurements. In addition, comparison to ozonesondes should be only done for near-simultaneous measurement and clear skies. It is not known if there will be enough routine ozonesonde measurements satisfying these conditions for a statistically significant validation.
Supporting Document:
World Meteorological Organization, Global Ozone Research and Monitoring Project Report No. 44, Chapter 4, Ozone Variability and Trends, 1999.
AIRS home page: http://www-airs.jpl.nasa.gov
SAGE-III home page: http://www-sage3.larc.nasa.gov
TOMS home page: http://toms.gsfc.nasa.gov
Funding: TBD

H.2.1.4 Trace Gases Validation (CDR)

Because of their effect on the global climate, trace gases have become an important field of study. The CrIS/ATMS suite will be able to retrieve abundances of trace gases (CH_4, CO, N_2O, and CO_2) in the atmosphere and therefore, the SDS may be producing a trace gas CDR. The algorithm for trace gas retrieval is similar to ozone and is readily implemented with minimal resource impact. In addition, the CO_2 measurements will improve the temperature retrieval whereas the CH_4 will improve the water retrieval. Most of the signal for trace gases comes from the middle troposphere. The signal from the boundary layer, though is typically buried in the overall noise and is more difficult to retrieve.

Gas	Wavenumber	Interfering	Geophysical Range	Time Scale	Measurement
CH_4	1250-1370	H_2O, N_2O, HNO_3,	1.7 ppmv 1% yearly	Months	Column
CO	2160-2195	H_2O, O_3, N_2O, CO_2	5-10,000 ppbv	Months	Column
N_2O	2220-2260	H_2O, CO_2, CO, O_3	300 ppbv	Decades	Zonal averages
CO_2	650-750 2250-2350	H_2O, O_3, N_2O	360 ppmv 0.4% yearly	Years	Calibration

Summary of the studies of Haskins and Kaplan (1993) on the ability of AIRS to retrieve trace gases.

CO column abundances accuracies of 10% may be possible with a vertical resolution of the upper and lower troposphere. CH4, with a strong 7.7 μm band and higher abundance than CO, may be able to be measured with an accuracy of 5-10%. Measurement uncertainties of 1% in CO_2 may be obtainable. N_2O will be measured with an accuracy of TBD

Approach 1: Comparison to EOS products
AIRS/AMSU/HSB, a sounding instrument suite that will also be in orbit at the time of the NPP mission, will be making similar ir/mw measurements with the ability to retrieve trace gas abundances. When these abundances become validated AIRS products, they will be ideally suited to validate the CrIS/ATMS trace gas products. Both data sets will be global in coverage and offer many data points at varied conditions to extensively validate the trace gas product. Other programs such as IASI, TES and In-situ data will be included in this effort.
Funding: TBD

H.2.2 Validation Approaches for Aerosol Products

TBD

H.2.3 Validation Approaches for Cloud Products

H.2.3.1 Cloud Ice Water Path (ATMS/VIIRS) (CDR)

Approach 1: Comparison to EOS and POES products
NOAA AMSU operational cloud ice water /particle size algorithm retrieves both IWP and particle effective diameter. These products are derived for thick ice clouds including precipitation conditions. Since ATMS has two channels similar to AMSU, the algorithm can be modified and tested with NPP ATMS and CrIS.
Funding: TBD

Approach 2: Comparison to Validation Site Data
Calculations of high-spectral resolution infrared radiances in cirrus cloud situations indicate that cloud forcing (clear minus cloudy) spectra are sensitive to ice particle size, ice water path, and cloud altitude. A numerical procedure based on the DISORT algorithm is used to retrieve the effective radius and ice water path of cloud layers with known optical depths and cloud boundaries and with nearby clear sky atmospheric conditions also known. The reasonable reproduction in a rather wide window region suggests that the DISORT based algorithm can distinguish small from large particle clouds as well as provide a fair estimate of IWP. Ice particle size and ice water path are estimated with 20% variation in the inferred values.
Funding: TBD

H.2.3.2 Cloud Liquid Water (ATMS/VIIRS) (CDR)

Approach 1: Comparison to EOS and POES products
NOAA AMSU operational algorithm retrieves both CLW and TPW. It is a physical retrieval algorithm which uses two AMSU primary channels at 23.8 and 31.4 GHz. These two frequencies are identical to ATMS channel selection. The algorithm can be directly modified for ATMS applications. Comparison between VIIRS and ATMS retrievals are also planned.
Funding: TBD

Approach 2: Comparison to Validation Site Data
Calculations of high-spectral resolution infrared radiances in cirrus cloud situations indicate that cloud forcing (clear minus cloudy) spectra are sensitive to ice particle size, ice water path, and cloud altitude. A numerical procedure based on the DISORT algorithm is used to retrieve the effective droplet size and water path of cloud layers with known optical depths and cloud boundaries and with nearby clear sky atmospheric conditions also known. The reasonable reproduction in a rather wide window region suggests that the DISORT based algorithm can distinguish small from large droplet clouds as well as provide a fair estimate of LWP.
Funding: TBD

H.2.4 Validation Approaches for Land Products

H.2.4.1 Atmospheric Corrected Reflectance Validation (CDR)

To be included.

H.2.4.2 Fire Area and Temperature Validation (CDR)

Approach 1: Comparison to EOS fire product
Statistical relationships will be established between AVHRR, MODIS and VIIRS-derived fire numbers over specific areas and time periods. Results of this study will be useful for the construction of a continuous AVHRR-MODIS-VIIRS data record of fire occurrences for long-term studies. VIIRS products will be evaluated for their physical limits, precision, and accuracy, using theoretical calculations and ground observations wherever available. These results will be compared with the VIIRS EDR requirements and recommendations will be made regarding VIIRS fire algorithm design. Potential for MODIS-VIIRS product stitching will be evaluated. Finally, it is also proposed to perform feasibility studies towards a time-integrated burned area product from VIIRS. This product eliminates most of the active fire misses due to clouds and low temporal resolution and thus is much more suitable for emission estimates and hazard assessment. Changes in the signal of near-IR channels from healthy vegetation to post-burning conditions will be studied and recommendations will be made for an operational algorithm.
Scope and Schedule:
Comparison and Accuracy:

Supporting Documents:
MODIS fire ATBD

Funding: TBD

H.2.4.3 LAI/FPAR Validation (CDR)

Approach 1 : Using EOS validation sites measurements

Primary Validation Data Source:

These products are often considered together since their computation and field measurement generally employ similar techniques. Plot-level validation data are available from field measurements acquired with commercial off-the-shelf instrumentation.

Ancillary Data Sources:

Additional validation data may include the 1 km MODIS LAI/FPAR product, provided its accuracy is sufficiently well characterized and the vegetation is known to be stable since the MODIS data acquisition. LAI is being measured fairly regularly at FLUXNET sites, consisting of eddy-covariance tower locations around the world. The accuracy of these data probably varies substantially. All major NASA land measurement campaigns (e.g., BOREAS, FIFE, etc.) include LAI assessment. Many of these historical data sets reside in the Oak Ridge National Laboratory DAAC.

Technique:

Generally, LAI or FPAR can be derived from hand-held instruments (including hemispherical view cameras) which assess light obscuration by vegetation canopy or crown. The instruments typically employ a modified form of Beers' Law to derive LAI or FPAR units. To determine LAI or FPAR at a plot scale, an investigator typically collects many samples over an area, then attempts to scale these "point" measurements to a larger area using fine-scale satellite or aircraft imagery. Although there is no current standard technique for either spatial sampling design or scaling, an LAI focus group under the auspices of the CEOS WGCV Land Product Validation Subgroup is developing a "Best Practices" handbook. Although historically the field instrumentation assumed a homogeneous distribution of leaf material, newer instrument specifically assess canopy clumping and reportedly produce superior results. In deciduous areas, "leaf drop baskets" are sometimes deployed to determine the LAI via the autumn leaf fall. Comparatively few FPAR validation studies have been conducted to date, and thus even fewer standards currently exist. Proper measurement requires measurement of four radiation fluxes upwelling and downwelling above the canopy, and the same between the canopy and the soil. Further, some canopy-absorbed PAR radiation is attributable to non-green leaf, stem or standing dead material; accurate FPAR measurements require knowledge of these quantities.

Scope and Schedule:

LAI and FPAR are key biophysical parameters, and are used in many modern regional and global climate and ecosystem models. However, field measurement of these parameters can require significant effort. Therefore, plot-level assessments are generally conducted episodically through the growing season. It is critically important that such sites be globally and ecologically stratified. Assessments along ecological gradients (e.g., precipitation) may allow more efficient data collection over a large range of values.
Leaf Area Index tends to be conserved over 1- to 2 week periods for most vegetation types, except during "green-up" or scenescent periods, or during harvesting for cropped areas. Therefore, in many cases, relatively few (~3) episodic measurement periods are sufficient

for validation. These measurements can be made at any time of day. Because FPAR is a radiative parameter, it varies with solar angle, atmospheric condition, soil moisture and canopy conditions. Its field measurement should therefore correspond to satellite overpass time. If canopy conditions are well-known, canopy radiative transfer models may provide accurate estimates for simple canopies (e.g., homogeneous grasslands) given measured LAI and leaf optical values.

Comparison and Accuracy:

Several significant error sources (e.g., ratio of green leaf area to plant area, canopy clumping, scaling) can make field assessment of these parameters fairly inaccurate. A reasonable estimate of LAI uncertainty is 0.2 for fairly uniform areas, and perhaps 0.5 elsewhere. Equivalent values for FPAR are about 0.075 and 0.15 (absolute).

Supporting Documents:

International Workshop on LAI Validation (2001), Best Practices for Field LAI Measurements, forthcoming.

Funding: TBD

H.2.5 Validation Approaches for Ocean Products

H.2.5.1 Ocean Color (Water Leaving Radiance) Validation (CDR)

Retrieval of normalized water leaving radiances for the ocean visible and near-IR bands from TOA radiances involves correction for numerous atmospheric effects and reflection of sky and sun light from the air-sea interface, as well a removal of small, but crucial instrument biases and effects. The initialization phase discussed under Level 1 validation using primarily data from the MOBY buoy and ship based measurements of in-water radiances and above water reflectances produces a consistent retrieval system comprised of the instrument data and atmospheric correction algorithm. This is discussed in detail in the MODIS ATBD for water-leaving radiances by Gordon. The resulting water-leaving radiances for the visible bands provide the basis for all other ocean color (ocean bio-optical) properties, including chlorophyll a and suspended sediment load. Therefore the careful validation of this SDR is crucial to ocean color products.

Approach 1: MOBY Comparisons

Primary Validation Source:

Marine Optical Spectrometer (MOS) instruments on MOBY or ship.

Ancillary Data Sources:

VIIRS data, nLw from heritage sensors on orbit, or historical MOBY servicing cruise data, MOBY calibration/characterization data

Techniques:

Automated collection of MOBY data at the time of VIIRS overpasses, and MOS data during MOBY servicing cruises within the swath, and development of a matchup data base to sample the useful range of VIIRS swath and sun angles. The overall approach for MOBY is discussed by Clark and Mueller in Chapter 11 of the Revised SeaWiFS Protocols for Calibration/Validation. Multiple radiometer buoys are maintained, and are deployed sequentially for three month intervals. Refurbishment and recalibration is done on shore. Optical collectors are cleaned monthly, and in-water calibration stability sources are employed before and after by divers. The measured spectral response function of the satellite sensor is convolved with the high resolution spectrometer data. Upwelled spectral radiances are collected at 3 depths and propagated to and through the surface to produce the desired water-leaving radiance values which are compared with the values retrieved from the satellite sensor.

Scope and Schedule:

The MOBY facility, located on Oahu and off Lanai, must be maintained continuously throughout the mission, and will provide daily observations. Useful matchups will be obtained for only a fraction of the days due to cloud obscuration and solar/scan geometry.

Comparison and Accuracy:

Through concentrated effort, including active participation of NIST personnel and facilities, the uncertainty of the MOBY water-leaving radiance time series is on order of 3%.

Funding:

Currently MOBY is funded via EOS (80%), SeaWiFS (10%), and NESDIS (10%) with annual total ~2M$/yr. Continued funding by EOS will likely decrease over the next few years, even with a planned shift from MODIS science team to EOS Project Validation Facility (analogous to AERONET). It is crucial that resources be identified to continue this national facility. IPO, NOAA, DOD contributions will likely be required.

Accuracy Requirements:

The goals for these measurements are an overall accuracy in an absolute sense of 2%, with a relative spectral (band-band) of 0.5%, over the time series.

Approach 2: Other In-water radiance measurements

A variety of instrumentation and protocols to make individual and time series of water-leaving radiance and also above water reflectance measurements from ship, moorings, drifting buoys, and permanent platforms have been developed. Details can be found at the SIMBIOS web site. These measurements, most by independent investigators, are very important for validation of the global water leaving radiance signals following initialization at the MOBY site. An extensive round robin comparison and inter-calibration network has been established, led by the SIMBIOS Project at GSFC and with participation by NIST, including US and many international programs. Included in this network are permanent locations on oceanic research towers and moorings. Absolute and relative uncertainty goals are as for MOBY. These are maintained through intercomparison activities, and use of portable stability sources during cruises and field programs. The SIMBIOS paradigm is that each ocean color flight project will mount a focused calibration validation program, with SIMBIOS serving as an inter-mission comparison facility, maintaining protocols, data bases for global intercomparisons, and center of expertise.

Funding: TBD

Approach 3: Validation using aircraft sensors

Use of aircraft sensors for validation of water-leaving radiances is primarily in the area of providing improved spatial variations and coverage. Maintaining sufficiently accurate absolute uncertainty of the instrument and its atmospheric correction for use in direct validation of water leaving radiance has improved significantly over the past decade..

Aircraft sensors show great utility in validation of bio-optical properties, but cannot provide the high degree of accuracy of in-water or shipboard observations at this time. Funding: TBD

H.2.5.2 Sea Surface Temperature (CDR)

Validation approaches proposed for the Sea Surface Temperature CDR is the same as the ones proposed for the Sea Surface Temperature EDR described in section H.1.5.1.

H.2.6 Validation Approaches for Snow and Ice CDR Products

TBD

Appendix I: Matrix of Who, What, When and How Much (from Co-Chairs)

Appendix J: Definitions

This Appendix provides a brief set of definitions to establish common language for the discussion of calibration and validation. The terms *accuracy*, *precision*, and *uncertainty* are used as defined in the Sensor Requirements Documents.

Calibration

Calibration is the process by which the output (usually a digital word) of an instrument is related to an input radiance, irradiance, or electromagnetic radiation signal. The input stimulus is generated such that it is related to a traceable standard. Depending on spectral region, sources/targets may have reflective and/or emissive properties.

Calibration Equation

Each photoactive element or feedhorn (with associated analog electronics and analog-to-digital converters) provides an output measured in digital numbers (DN) when it is stimulated by incident radiation. The plot of incident radiance versus DN is termed the radiometric transfer curve. The objective of radiometric calibration is to develop a calibration equation which best represents the observed radiometric transfer curve, and to provide both a quantitative determination of the gain coefficients and zero-input bias (offset) of the equation, as well as the uncertainties in measuring radiances using these coefficients. Radiometric calibration is best conducted using a full-aperture source that is spectrally and spatially homogeneous. Multiple radiometric levels are used, spanning that portion of the sensor dynamic range that is representative of the scene dynamic range in given spectral regions. Uncertainties are inherent in the design and measurement of the source itself. Instrument characteristics add other uncertainties. Calibration assigns precision and accuracy values to all contributors to errors associated in determining a "true" scene radiance value for a given digital number. A number of optical (antenna pattern) and electronic crosstalk effects are usually observed during pre-launch test and orbital operations. The calibration equation is modified to ameliorate the impact of these effects. Aging and environmental conditions cause changes in the gain coefficients and signal offset. These are characterized over the life cycle of the instrument.

The set of calibration equations for each instrument is the basis for the radiometric part of the Level 1B product. Further radiometric adjustments may be necessary after geometric re-sampling of the product to register spectral bands to one another and to the surface of the Earth.

Characterization

This defines the output response in terms of variations within the instrument field-of-view and field-of-regard, of changes in instrument temperature, of power supply variations, of instrument modes of operation, or due to any other parameter that causes a measurable change in response for a calibrated/fixed/constant external input. The part of characterization that deals with changes over time is segregated and identified as *calibration trending*.

Error Analysis

During pre-flight calibration, an Error Analysis is used to estimate the uncertainty in the inverse regression from the radiometric equation (i.e., the uncertainty in measured radiance for a given DN). Error Interval Analysis defines the number of radiometric levels to be used during calibration, as well as the number of independent data repetitions. This tool continues to be used through the post-launch period to estimate uncertainties in the radiance computed by the SDS.

Field-of-View (FOV)

Every electro-optic or microwave instrument has a means of focussing energy onto a transducer that converts the input to a current, voltage, or change in impedance. The limit in object space of the angular extent of the radiation field that can place energy on the transducer is the field-of-view. In an ideally baffled instrument the FOV is identical to the extent of the angular subtence of the focal plane.

Field-of Regard (FOR)

The FOR is the angular space/volume through which the FOV of an instrument can be pointed. In the case of a cross-track or conical scanning instrument, the field-of-regard can have several active segments. There is the imaging FOR (the Earth's surface and atmosphere), the calibration target FOR (cold space, solar diffuser, calibration lamps, blackbody), and the scan cavity (noise and serendipity).

Trending

Trending is the process initiated at the time of first measurement and extending through the post-launch periods. Drifts in performance are tracked and used to refine databases that permit instrument measurements to be related to actual/estimated signals at the instrument aperture.

In this document, trending is primarily a post-launch activity.

Validation

Validation has two contexts. For the hardware community "validation" of instrument performance should be thought of as instrument performance verification. For the science community, validation emphasizes algorithm products and establishes the accuracy of these products over a range of operating conditions and for a variety of science environmental conditions.

In this document, validation is the process of assessing by independent means the uncertainties of the data products derived from the system outputs.

General Validation Approaches

Direct Comparison with Independent Correlative Measurements

- Ground- based Networks
- Comprehensive Test Sites
- Field Campaigns
- Comparisons with Independent Satellite Retrievals

Products from Instruments on the same satellite platform
Products from Instruments on different satellite platforms: IPO, NASA, international

Basic Stages of Science Validation

Pre-launch - emphasis on algorithm development and characterization of uncertainties from parameterizations and algorithmic implementation

Post-launch - emphasis on algorithm refinement and data product assessments

Selected Project Definitions

Ancillary Data: Data outside of the NPP mission system used to generate NPP products, ex: NWP, DEMs.

Auxiliary Data: Data generated/provided by the spacecraft to be either included with the instrument data and/or transmitted as part of the S-band telemetry data

Granule: The smallest aggregation of data which is independently managed (i,e., described, inventoried, retrievable).

Instrument Developers: This provides a shorthand description of the joint agency development of instruments for NPP. The IPO has responsibility to manage the contracts for the CrIS and VIIRS instruments. NASA has contract responsibility for the ATMS. The "developers" are the government agencies. The instrument "contractors" are the instrument/algorithm designers and builders using the Government RDRs and EDRs as the end-to-end requirements.

Investigators' Team: A group of science investigators selected through a NASA Research Announcement to participate in NPP instrument development advisories, research science Climate Data Record development and validation, and selected EDR validation.

IPO Science Team: A group of science and engineering investigators on any one of the IPO research and risk-reduction thrust areas for the NPP and NPOESS programs. These teams often support on-going validation tasks for the POES, DMSP and EOS programs.

Level 0: Raw instrument data at original resolution, time ordered, with duplicate packets removed.

Level 1A: Reconstructed unprocessed instrument/payload data at full resolution; any and all communications artifacts (e.g. synchronization frames, communications headers) removed.

Level 1B and SDR: Instrument data that has been radiometrically corrected and geolocated. They are fully time-ordered and overlap removed. The Level 1B algorithm developed at SDS will be different from the one used by IDPS.

Metadata: Information about data. Provides a description of the data including instrument, type of data, location of data, and quality of data.

OATS: The Operational Algorithm Teams that support the development of NPP instruments. The OATS are IPO peer science panels. There is a VIIRS OAT (VOAT), a Sounder Suite OAT (SOAT), a microwave OAT (MOAT) and within the sounder suites a Ozone OAT (OOAT) and a GPS Occultation Sensor OAT and a Space Environment Sensor Suite (SESS) OAT.

Raw Data Record: Data in their original packets, as received from the observer.

CAL LUTs: Calibration Look-Up-Tables (LUT) derived for NPP instruments at the IDPS or at the SDS.

Verification: The process of ensuring mission/segment requirements is satisfied. Verification occurs using one or more methods (analysis, test, demonstration, or inspection).

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Appendix L: Acronyms

ABI - Advanced Baseline Imager
ACARS - Aeronautical Radio Incorporated Communications Addressing and Reporting System
ACE - Aerosol Characterization Experiment
ADEOS - Advanced Earth Observing Satellite
ADS - Archive and Distribution Segment
AER - Atmospheric and Environmental Research Inc
AERI - Atmospheric Emitted Radiance Interferometer
AERONET - Aerosol Robotic Network
AFWA - Air Force Weather Agency
AIRS - Atmospheric Infrared Sounder
AMSR - Advanced Microwave Scanning Radiometer
AMSU - Advanced Microwave Sounding Unit
AOD - Aerosol Optical Depth
AOS - Acquisition of Signal or Advanced Orbiting Systems
AOT - Aerosol Optical Thickness
APL - Applied Physics Laboratory
APMIR - Airborne Polarmetric Microwave Imaging Radiometer
AQUA - Afternoon EOS spaceborne platform (PM1)
ARAD - Atmospheric Research and Applications Division
ARM - Atmospheric Radiation Measurement (DOE)
ARSCL - Active Remotely Sensed Cloud Layers
ASTER - Advanced Spaceborne Thermal Emission Radiometer
ATMS - Advanced Technology Microwave Sounder
ATOVS - Advanced TOVS
AVHRR - Advanced Very High Resolution Radiometer
AVIRIS - Airborne Visible Infrared Imaging Spectrometer

BALTEX - Baltic Sea Experiment
BALTRAD - BALTEX Radar Data
BBR - Band to Band Registration
BCS - Blackbody Calibration Srource
BOREAS - Boreal Ecosystem-Atmosphere Study
BRDF - Bi-directional Reflectance Distribution Function
BSRN - Baseline Surface Radiation Network

C3 - Command, Control and Communications
CALVEX - Calibration Validation Experiment
CAMEX - Convection and Moisture Experiment
CART - Clouds and Radiation Testbed
CC/L Cloud Cover/Layer
CCS - Climate Calibration Service
CCSDS - Consultative Committee for Space Data Systems

CDR - Climate Data Record
CERES - Clouds and the Earth's Radiant Energy System
CHAMEX - Cloud Height and Motion Experiment
CHEM - Named EOS AURA, part of NASA EOS spaceborne platforms, and follows Terra and Aqua
CIGSN - Continental Integrated Ground Site Network (Australia)
CIMSS - Cooperative Institute for Meteorological Satellite Studies
CLAMS - Chesapeake Lighthouse and Aircraft Measurements
CLAP - Central Laboratory of Air Pollution
CLI - Canopy Lidar Initiative
CLS - Cloud Lidars
CLW - Cloud Liquid Water
CMDL - Climate Monitoring and Diagnostics Laboratory
CMIS - Conical scanning Microwave Imager/Sounder
CPI - Cloud Particle Imager
CRYSTAL - Cirrus Regional Study of Tropical Anvils and Cirrus Layers
CrIS - Cross track Infrared Sounder
CrIMSS - Cross-Track Infrared/Microwave Sounder Suite
CTP - Cloud-Top Pressure
CWV - Cloud Water Vapor

DAAC - Data Active Archive Center
DB - Direct Broadcast
DEM - Digital Elevation Model
DISORT - DIScrete Ordinate method Radiative Transfer
DMSP - Defense Meteorolgical Satellite Program
DOC - Department Of Commerce
DOE - Department of Energy
DOD - Department of Defense
DPI - Derived Product Image

EDR - Environmental Data Record
EMD - Engineering and Manufactoring Development
EO-3 - Earth Observing 3
EOS - Earth Observing System
ESA - European Space Agency
ETM+ - Enhanced Thematic Mapper Plus
EUMETSAT - EUropean organization for the exploitation for METeorological SATellites
EVS - Emission Versus Scan

FARS - Facility for Atmospheric Remote Sensing
FASCAL - Facility for Automated Spectral Irradiance and Radiance Calibrations
FFT - Fourier function transform
FIFE - First ISLSCP (International Satellite Land Surface Climatology Project) Field Experiment (FIFE)

FIRSC - Far-InfraRed Sensor for Cirrus
FOV - field of view
FPA - Focal Plane Arrays
FPAR - Fraction Photosynthetically Active Radiation
FTIR - Fourier Transform Infrared

FTS - Fourier Transform Spectrometer
FY - Fiscal Year

GCST - Global Climate Science Team
GEO - Geo-stationary Earth Orbit
GHz - Giga-Hertz
GIFTS - Geostationary Imaging Fourier Transform Spectrometer
GLI - Global Imager
GMS - geostationary Meteorological Satellite (Japan)
GOES - Geostationary Operational Environmental Satellite
GPS - Global Positioning System
GSE - Ground Support Equipment
GSFC - Goddard Space Flight Center

HAPEX-Sahel – Hydrology-Atmosphere Pilot Experiment in the Sahel
HIRS - High resolution Infrared Radiation Sounder
HIS - High-resolution Interferometer Sounder
HSB - Humidity Sounder for Brasil

IAC - Integrated Alignment Collimator
IASI - Infrared Atmospheric Sounding Interferometer

IDPS - Interface Data Processing Segment
IGBP - International Geosphere-Biosphere Programme
IGS - Internal Governmental Studies NPOESS IPO Program
ILS - Instrument Line Shape
IORD - Integrated Operational Requirements Document
IPO - Integrated Program Office
IPT - Integrated Product Team
IR - InfraRed
IWP - Integrated Water Profile

Kbps - Kilobits per second

LEO - Low Earth Orbit
LAI - Leaf Area Index
LaRC - Langley Research Center
LASE - Lidar Atmospheric Sensing Experiment
LBA - Large Scale Biosphere-Atmosphere Experiment in Amazonia
LBL - Line By Line
LBLRTM – Line-By-Line Radiative Transfer Model

LSS - Launch Support Segment
LST - Land Surface Temperature
LSU - Louisiana State University
LTER - Long Term Ecological Research
LUTs - Look-Up-Tables
LV - Launch Vehicle
LWIR - Long Wave InfraRed
LWP - Liquid Water Path

M-AERI - Marine AERI
MAS - MODIS Airborne Simulator
MASTER – MODIS/ASTER Airborne Sensors
MBIR - Medium Background Infrared
Mbps - Megabits per second
MCST - MODIS characterization Support Team
MCV -
MERIS - MEdium Resolution Imaging Specrometer
METEOSAT - METEOrological SATellite
METOP - Meteorological Operational Platform
MHS - Microwave Humidity Sounder
MHz - Mega-Hertz
MISR - Multi-angle Imaging Spectro-Radiometer
MIT - Massachusetts Institute of Technology
MMCR - Millimeter Wave Cloud Radar
MOBY - Marine Optical Buoy
MOCE - Marine Optical Characterization Experiment
MODIS - Moderate resolution Imaging Spectroradiometer
MOPITT - Measurements of Pollution in the Troposphere
MPL - Micropulse Lidar
MQUALS - MODIS Quick Airborne Looks
MTF - modulation transfer function
MWIR - Middle Wave InfraRed

NASA - National Aeronautics and Space Administration
NAST - NPOESS Airborne Sounder Testbed
NAST-I - NPOESS Airborne Sounder Testbed-Interferometer
NAST-M - NPOESS Airborne Sounder Testbed-Microwave
NAVOCEANO - Naval Oceanographic Office
NCEP - National Center for Environmental Prediction
NCST - NPP Characterization Support Team
NDVI - Normalized Difference Vegetation Index
NEDT - noise equivalent temperature or noise equivalent delta-T
NESDIS - National Environmental Satellite, Data, and Information Service
NESR - Noise Equivalent Spectral Radiance
NIR - Near-infrared
NIST - National Institute of Standards and Technology

NMP - New Millennium Program
NOAA - National Oceanographic and Atmospheric Administration
NOHRSC - National Operational Hydrologic Remote Sensing CenterNORPEX – Northern Pacific Experiment
NPOESS - National Polar-orbiting Operational Environmental Satellite System
NPP - NPOESS Preparatory Project
NRA - NASA Research Announcement
NSA- North Slope Alaska
NSF - National Science Foundation
NWP - Numerical Weather Prediction
NWS - National Weather Service

OATs - Operational Algorithm Teams
OBC - On-Board Blackbody Calibration
OCTS - Ocean Color and temperature Scanner
OLS - Operational Linescan System
OPD - Optical Path Difference
ORA - Office of Research and Applications
ORNL - Oak Ridge National Laboratory
OSDPD - Office of Satellite Data Processing and Distribution
OSS - Optimal Spectral Sampling

P-AERI - Polar- AERI
PFAAST
PIDCAP - Pilot Study for Intensive Data Collection and Analysis of Precipitation
POES - Polar Operational Environmental Satellite
PRT - Platinum Resistance Thermometer
PSA - Polarization Source Assembly
PSO - Project Science Office
PSR - Polarimetric Scanning Radiometer

RDR - Raw Data Record
RF - Radio Frequency
RMS - root mean square
RSR - Relative Spectral Response
RVS - Response Versus Scan

6S - Second Simulation of Satellite Signal in the Solar Spectrum
S-AERI -
SAFARI - South African Regional Science Initiative
SAGE - Stratospheric Aerosol and Gas Experiment
SALSA - Semi-Arid Land Surface Atmosphere
SBRS - Santa Barbara Remote Sensing
SCP - Satellite Cloud Product
SD - Solar Diffuser
SDR - Sensor Data Record

SDS - Science Data Segment
SDSM - Solar Diffuser Stability Monitor
SeaWIFS - Sea-Viewing Wild Field of View
SGP - South Great Plain
S-HIS - Scanner-HIS
SHDOM - Spherical Harmonic Discrete Ordinate Method
SIS - Spherical Integrating Source
SIRCUS - Spectral Irradiance and Radiance Responsivity Calibrations with Uniform Sources
SPMA - Spectral Measurement Assembly
SRF - Spatial Response Function
SSA - S-band Single Access
SSEC - Space Science and Engineering Center
SSM/I - Special Sensor Microwave/Imager
SSPR – Shared System Performance Responsibility
SST - Sea Surface Temperature
SURFRAD - Monitoring Surface Radiation in the Continental United States
SVS - Space View Source
SVWXEX- To be supplied
SWIR Short-wave infrared

TBD - To Be Determined
TBR - To Be Resolved
TBS - To Be Supplied
TCEX - To be supplied
Terra - Morning EOS spaceborne platform (EO1)
TES - Tropospheric Emission Spectrometer
THORPEX - The Hemispheric Observing System Research and Predictability Experiment
TIROS - Television InfraRed Operational Satellite
TOA - Top of the Atmosphere
TOMS - Total Ozone Mapping Spectrometer
TOVS - TIROS Operational Vertical Sounder
TPW - Total Precipitable Water
TRACE- Transport and Chemistry near the Equator
TRMM - Tropical Rainfall Measuring Mission
SSPR - Sharedl System Performance Responsibilities
TXR - Thermal-infrared Transfer Radiometer
TV - Thermal Vacuum
TWP - Tropical Western Pacific

UMBC - University of Maryland at Baltimore County
UMD - University of Maryland
UPS - U.S. Postal Office
USGS - U.S. Geological Survey
USWRP - United States Weather research Program

VIS - Visible
VIRS - Visible Infrared Scanner
VIIRS - Visible Infrared Imaging Radiometer Suite

WINTEX - Winter Experiment
WVIOP - Water Vapor Intensive Operational Periods
WVSS - Water Vapor Sensing System

ZPD - Zero Path Difference